BIOLOGY

A Textbook for Higher Secondary Schools

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BIOLOGY

A Textbook for
Higher Secondary Schools

SECTION 4
Plant and Animal Physiology

AND

SECTION 5
Self-Perpetuation or Reproduction

Edited by
P. MAHESHWARI FRS
and
MANOHAR LAL

National Council of Educational Research and Training

ACKNOWLEDGEMENT

The National Council of Educational Research and Training has undertaken a major programme to prepare model textbooks in various subjects for the school curriculum. For this purpose, the Council has set up a Central Committee for Educational Literature to guide and direct the programme. Panels of specialists have been set up by the Central Committee to develop curricula and to write textbooks, teachers' resource books and other materials on subjects at school level.

The Biology Textbook Panel under the Chairmanship of Prof P. Maheshwari, Head of the Department of Botany, Delhi University has during the last two years developed curriculum, syllabus and textbook of Biology for higher secondary classes.

The Biology curriculum and text material were reviewed by practising teachers and science educators before they were finalised. Sections 1, 2 and 3 of the textbook relating to 'Some Basic Facts About Life', 'The Diversity of Plant Life' and 'The Diversity of Animal Life' respectively have since been published and adopted by the higher secondary schools affiliated to the Central Board of Secondary Education. The present publication deals with Sections 4 and 5 of the series that are devoted to 'Plant and Animal Physiology' and 'Self-Perpetuation or Reproduction.'

The National Council wishes to thank Prof. P. Maheshwari, the Chairman, and members of the Biology Panel for their valuable contribution to the preparation of the Biology books.

The two remaining sections of the textbook will be published in the course of 1966. It is also proposed to publish one single volume amalgamating all the seven sections.

The National Council invites suggestions on the Biology series from teachers and science educators.

L.S. CHANDRAKANT
Joint Director
National Council of Educational Research and Training

New Delhi
May 1966

Foreword

FOR several years I have seriously felt the lack of good school and college textbooks on biology. Most of the existing books emphasize only the descriptive aspects of the subject, largely ignoring the newer and more fundamental concepts. This is, in part at least, responsible for adversely influencing the public image of biology and for relegating it to a subordinate position in the list of sciences. No thinking person can doubt that biology profoundly affects the life of all human beings and its study is one of the most essential requisites of every responsible and intelligent citizen. Further, the study of biology must begin right in the school as an integral part of any course in science instead of being postponed to the college or university stage. The pupil's choice of the subject of his future study is determined, to a large extent, by the courses he has attended in school and by the type of text matter presented to him at this stage.

Recognizing the above facts, I readily accepted the invitation of the National Council of Educational Research and Training to act as Chairman of the Panel set up to prepare a new and modern textbook suited for use in Indian Secondary Schools.

This publication comprises the fourth and fifth sections of the textbook. It deals with 'Plant and Animal Physiology' and 'Self-Perpetuation or Reproduction'. The subsequent sections will be brought out in due course and when they are all ready the book will also be produced as a single bound unit.

It may be noted that there are several ways of approaching the subject of biology, each having its own merits and demerits. The editors and members of the Panel are convinced that a wide acquaintance with a number of different kinds of organisms, their activities, their habits and their tissues and organs, is essential and basic to the understanding of the general concepts of evolution, ecology, heredity and cell physiology. This approach, in their opinion, combines not only the pedagogical advantage of proceeding from the known to the unknown but also prevents students from getting lost in the intricacies of the more advanced aspects of biology.

Although evolution is treated separately in two chapters, an attempt has nevertheless been made to acquaint the student with this all pervasive principle during his study of the world of life. Biological phenomena common to plants and animals have been discussed together as far as possible. Technical terms have been kept down to the minimum except when their use is believed to contribute to easier communication and understanding. Important biological discoveries have been dealt with in a historical perspective to give an idea of how science progresses.

It has been our objective to present the subject in an understandable, stimulating and instructive fashion. We shall appreciate receiving comments, criticisms and suggestions. These will be taken into account in bringing out a revised version of the book.

The original drafts of the chapters in the book were contributed by several persons whose names are given below in alphabetical order: Dr. R.N. Chopra, Reader in Botany, University of Delhi; Mrs E. Gonzalves, Biology Department, St. Xavier's College, Bombay; Prof. N.B. Inamdar, Head of the Department of Zoology, Institute of Science, Bombay; Prof. B.M. Johri, Department of Botany, University of Delhi; Dr. G.N. Johri, School of Studies in Zoology, Vikram University, Ujjain; Dr. L.N. Johri, Reader in Zoology, University of Delhi; Dr. M.S. Kanungo, Reader in Zoology, Banaras Hindu University; Dr. Manohar Lal, Department of Botany, University of Delhi; Dr. S.C. Maheshwari, Reader in Botany, University of Delhi; Dr. L.P. Mall, Reader in Botany, Vikram University, Ujjain; Prof. R.D. Misra, Head of the Department of Botany, Banaras Hindu University; Dr. H.Y. Mohan Ram, Reader in Botany, University of Delhi; Prof. M.R.N. Prasad, Department of Zoology, University of Delhi; Dr. B. Tiagi, Reader in Botany, University of Rajasthan, Jaipur; and Dr. H.S. Vishnoi, Department of Zoology, University of Delhi.

There was naturally a good deal of editing work to be done in order to bring the manuscripts into a form suitable for publication, and to add the illustrations to make the text understandable. In this I was ably assisted by my colleague Dr. Manohar Lal whose help was invaluable in looking after the large volume of work associated with such a project.

I was receiving the ungrudging help of several other persons among whom special mention must be made of Drs. G.S. Paliwal, Sipra Guha and Man Mohan Johri and Messrs T.S. Rangan and S.S. Bhojwani of the Botany Department, University of Delhi, who looked after much of the day to day routine and the reading of the proofs. Prof. Ralph Buchsbaum of the Department of Zoology, University of Pittsburgh, and Dr. R. Will Burnett of the Teachers College, Columbia University Team in India critically read through Section 3 on animals; Prof. W.N. Stewart of the Department of Botany, University of Illinois, gave many useful comments on Section 2

dealing with plants; Dr. S.S. Sehgal extended valuable help in preparing and checking up illustrations for Section 3; and Dr. S.C. Maheshwari of the Department of Botany, University of Delhi, read Section 4 on physiology. Two school teachers—Mr S.M. Sharma of the Harcourt Butler Higher Secondary School, New Delhi, and Miss Katherine Bolton, formerly of St. Thomas Girls' Higher Secondary School, New Delhi—went through some of the chapters and offered several helpful suggestions. The help received in the form of photographs and other copyright material is acknowledged in the captions Figures 26.9, 27.6 and 28.1 have been taken from *Natue*, a part of the Macdonald Illustrated Library.

I must add that the book might never have seen the light of the day but for the constant help and generous co-operation of the following officers of the National Council of Educational Research and Training: Mr Raja Roy Singh, former Joint Director; Mr L.S. Chandrakant, Joint Director; Mr P.N. Natu, Secretary; Dr. R.N. Rai, Head of the Department of Science Education; Mrs S. Doraiswami and Mrs A. Krishnaswami, former Chief Publication Officers; Mr Abul Hasan, Chief Publication Officer, and Mr S. Doraiswami, Secretary of the Biology Panel.

P. MAHESHWARI
Chairman, Biology Panel
National Council of Educational Research and Training

Delhi
May 1966

Preface

IN the midst of the present remarkable achievements in rocketry, nuclear energy, synthetic plastics and fibres, and exploration of space, the study of living organisms, their functions and their importance is frequently minimized or overlooked. It is often forgotten that the primary aim of science, apart from the satisfaction of intellectual curiosity, is the survival and welfare of man. Nothing has contributed more to human welfare and to the very emergence of man from his early animal behaviour than the knowledge of plants, animals and his own body. It is said that there are four chief ravages of humanity—diseases, wars, famine, and now over-population. From man's point of view, therefore, biology is the most fundamental and important of all the sciences. It affects vital state policies on matters like conservation of natural and human resources, radiation experiments, population control, quarantine and health programmes. Biology also helps us answer such personal questions as: what determines sex; who is responsible for the sex of the baby, the mother or the father; how are twins born; why do babies resemble their parents; how do we acquire immunity against a disease; why do we become enfeebled in old age; how are plants and animals interdependent; and so on. Sanitation, nutrition, pest control, and other attributes of intelligent citizenship, all require a biological background. Finally, biology—a study of the unity as well as the diversity of plant and animal life—is an intellectually enlightening and aesthetically satisfying experience. Indeed, in view of its importance in everyday life, biology should be made a compulsory subject for all school boys and girls. For all this we need adequate textbooks which present the subject in a satisfactory manner keeping in view the needs of the country for which the book is written. The present book is an attempt in that direction.

Should Botany and Zoology be Taught as Separate Subjects? The book adopts, in so far as possible, a common treatment of plants and animals and attempts to emphasize the basic unity in the organization and functioning of living matter. This might appear at first sight to be rather undesirable to those who are used to teaching botany and zoology as separate, well-defined subjects with little or no similarity. They might indeed question

the commonness between a cow and a 'neem' tree. To such critics we owe an explanation right in the beginning.

In the nineteenth century there was a tendency towards compartmentalization of subjects but the insight into the life processes acquired in the past 50 years has shown how these compartments merge into each other. Recent work on cell physiology with the newer techniques of biochemistry and biophysics has particularly called attention to a basic commonness between plants and animals. This common ground also extends into the fields of genetics, cytology, evolution, physiology and electron microscopy. There is no reason why at the higher secondary stage the student should not be apprised of these broadening horizons. So far as some other aspects are concerned, the book still retains separate sections on plants and animals. It may be added that in English and American schools a composite biology course has been in use for the last 10 to 15 years, and some universities too have recently begun to offer similar courses at the B.Sc. level.

Even at the research level, many well-known laboratories in the UK and the USA have a common unit for work on both plants and animals. If we are to train the younger generation for successful careers in biological research, it is necessary to orient our school courses in such a way that they get the right perspective of the subject It may also be pointed out that the school biology course would be the only one which many of our boys and girls will ever attend in their life.

Biology in the Twentieth Century. The nineteenth century biologists concerned themselves mainly with the morphology and anatomy of plants and animals. While this was natural, the subject has undergone much change in its content and character in the twentieth century. This has been made possible largely by the availability of new techniques of chemistry and physics although many milestones have also been laid purely by keen observation and logical analysis. The rediscovery of Mendel's laws of heredity infused new interest into the field of genetics, and the mechanism of inheritance was firmly established. Artificial means of inducing mutations in plants and animals were discovered and the genes responsible for the expression of a particular character were pin-pointed. Electron microscopy, ultra-centrifugation, spectrophotometry and other techniques have further unravelled the intricate machinery of the living cell, and these studies have now gone as far as the isolation and artificial synthesis of the hereditary substance—DNA. The study of enzymes, which was a minor discipline in the last century, has grown into a vast area of research. Our knowledge of vitamins, hormones and antibiotics is also a gift of the present century biology. An understanding of the mechanism of nerve action, brain functioning, photosynthesis, respiration and a host of other physiological processes is also derived from the researches of the last 40 years. To this list may be added the still more recent disciplines like virology, radiation and space biology, the cure for cancer and heart diseases, and finally the attempts to synthesize life itself!

Thus, the emphasis has largely shifted from a descriptive and morphological treatment to the functional aspects. It is apparent that if we continue to train our students only in nineteenth century biology, as indeed is being done in most of our schools and colleges, they will find themselves unsuited to the future needs of the scientific world.

The Need For Change. One factor which makes the existing course rather dull is that its contents are mostly or entirely descriptive. We think that the morphological part must still form the basis of biology and has to be done well, but this cannot be the only part, and that physiology, ecology, evolution, the interrelations between plants and animals and the role of biology in human life are subjects that cannot be left out of consideration. A large fund of biological information acquired during the present century finds no mention in most Indian texts which also do not provide any information about the interdependence of plants and animals. Indeed, many of the existing books are as much as 50 years behind current biological thought. It is perhaps true that some aspects of biology, involving a rather intensive knowledge of chemistry and physics, are too advanced and complicated to be understood by the school student. However, recent tests on the learning potential of young students have clearly shown that the general principles of physiology and genetics can be effectively taught provided a simple and popular approach is adopted and there is some demonstration material for illustration. For instance, problems like what happens in photosynthesis, or respiration, or how living organisms respond to external and internal stimuli, elicit greater interest in the minds of students than learning the characters of a family of plants or describing the pectoral girdle of frog. Similarly, on the practical side, the young student will take much greater interest in experimenting on the digestion of starch by an enzyme than in sketching the shapes of leaves and bones. It would be appalling if a school student should get the impression that biology is nothing more than cutting up frogs and collecting hay, or just a system of naming plants and animals in an unfamiliar language.

It is sometimes argued that our textbooks are already encyclopaedic and that it is hardly possible to add more material in view of the time at the disposal of the students. This no doubt poses some difficulty because scientific knowledge is doubling itself every 10 to 15 years. Indeed, the twentieth century has provided far more scientific information than the last 5,000 years. This knowledge must naturally be incorporated into broad biological concepts so as to become a part of our everyday thinking. To do this one has obviously to cut out certain portions. Such facts as are only of an additive nature or matters of unnecessary detail must therefore be pruned, and the dead wood removed here and there. To take a specific instance, a student need not spend too much time in learning the variations in the organization of flowers or vertebrae. Since everything cannot be taught at the school stage, a judicial balance has to be struck between depth and breadth.

Another surprising factor is that in the past the courses in India in this subject have virtually excluded the study of human biology. While the students have been studying in detail the various types of roots and stems as well as the smallest bones of a frog, they remained wholly ignorant of their own body.

The Book. The book has been divided into seven, more or less independent sections. In the first section the student is introduced to the subject matter of science, particularly biology, and the characteristics of the living matter. A glimpse of the variety of plant and animal life prepares the student for a more detailed study of these forms in the sècond and third sections. The fourth section treats the main physiological processes in animals and plants in a simple way. The fifth is devoted to a comparative account of the different modes of reproduction in plant and animal kingdoms. Heredity, evolution and ecology form the sixth section of the book. The epilogue to the book covers topics like human diseases, interdependence of plants and animals and the role of biology in human welfare.

We have much pleasure in presenting this book to the students and teachers of the Higher Secondary Classes and shall try to incorporate any suggestions for improvement in the next edition.

Department of Botany
University of Delhi.

Editors : P. MAHESHWARI
MANOHAR LAL

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SECTION 4

Plant and Animal Physiology

CHAPTER 38

On Being Alive

IF you were to study the working of a motor car, how would you proceed about it? Perhaps you will first watch different kinds of cars and then try to study the parts such as the wheels, brake, clutch, accelerator, engine and so on. Next, you may want to know how the car actually moves—where the petrol is burnt, and how the energy derived from it is directed to move the wheels. In trying to understand how a human being or for that matter any living thing functions, scientists follow almost the same method. In the preceding three sections you were given an idea of the variety of plants and animals that inhabit the earth, their activities, their habits, and their tissues and organs. We shall now learn what type of substances exist in cells, how the machinery of an organism works and what it means to be alive!

Living things, as you have seen, are made of either single cells or of groups of cells. In the protozoa, bacteria and some other simple organisms the individual is a single isolated cell that carries on all the life processes like nutrition, respiration, growth, excretion and reproduction. The same life processes are also carried on by multicelled organisms but there is a division of labour. Separate tissues are set aside to do different jobs. Thus there is muscular tissue, nerve tissue, photosynthetic tissue, and so on. Each of these tissues is specialized to do one kind of work. However, all the cells are potentially capable of living independently. It is, therefore, clear that the common denominator in all living organisms is the cell. It is not only the unit of structure but also the unit of function. Be it the digestion of food or the sudden drooping of the leaves of *Mimosa*, or any other process, everything results from the activities of the cells composing the respective system. Consequently, we can understand a great deal about life processes if we analyse the behaviour of a single cell.

Let us have a fresh look at the activities of a single-celled organism like *Amoeba*. It moves about by putting forth a number of small processes or pseudopods; it engulfs food from the surrounding medium, digests it and builds up its protoplasm; it throws out the waste materials; and in due course it divides into two daughter amoebas. Obviously, to accomplish all this, thousands of chemical reactions must go on simultaneously in the cell. Indeed, some people have likened a living cell to a factory where raw materials are obtained from outside and processed in numerous ways into a variety of products. A continuous supply of energy is necessary to keep the factory running. The nucleus in the cell is comparable to the director of a factory, and the cytoplasm is

the seat of most of the reactions. We shall soon study some of the important processes which occur in this tiny but wonderfully organized factory—the cell.

The Composition of Protoplasm

Since protoplasm is the unique living stuff, you might think that it contains some unusual elements which are absent from non-living objects. This is not so. Protoplasm is made up of the sa occur in many lifeless thing sand, air and water. Abo enter into the composition of the more abundant amon carbon, hydrogen, nitroge which constitute about 99 p weight of protoplasm. Fig you an idea of the element body. In addition to thes and boron also occur in tl

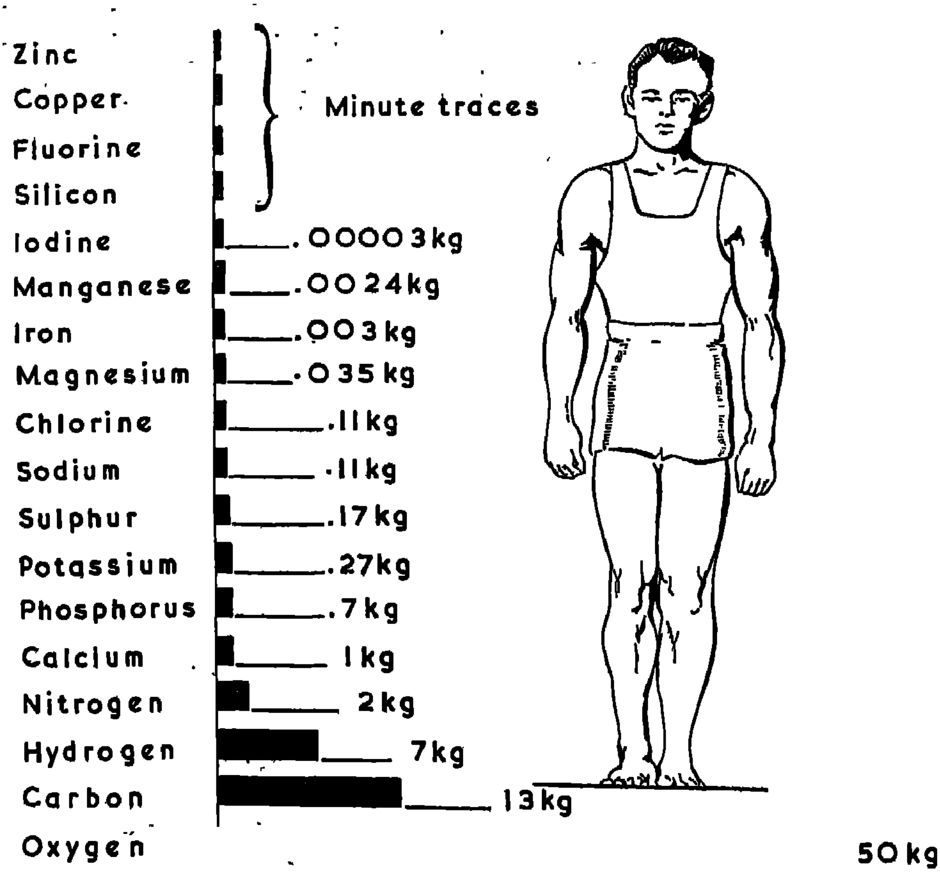

Fig. 38.1. The 18 elements essential to life are found in the amounts shown, in a man weighing 75 kilograms. Adapted from T.J. Moon, J.H. Otto and A. Towle, *Modern Biology*, Holt, Rinehart and Winston, Inc., New York, 1960.

plants. It is, however, not the elements but the compounds formed from them which make living protoplasm different from other substances. There are thousands of compounds that have been recognized in the protoplasm. Of these some need special mention. These are water, mineral salts, carbohydrates, fats, proteins and nucleic acids. You might ask: "Can we make living protoplasm by mixing these substances?" So far the answer is NO. The chemical compounds found in protoplasm are mixed together in such a complicated manner that it is not easy to copy this organization. If we succeed in arranging them in the right manner, we shall then have created life itself. It should also be noted that the protoplasm of one organism, say a bean plant, is not chemically identical with that of another organism such as mango. Not only that, cells from different organs of the same individual may also contain different substances. As a matter of fact the composition of protoplasm of a single cell keeps on changing as new materials are synthesized and foods are used up. However, the following compounds are always present in the protoplasm.

1. Water. All cells contain fairly large amounts of water. In some aquatic plants it may form as much as 96 per cent of the total weight. In human beings it amounts to 80 per cent in brain cells and 66 per cent in the rest of the body. Blood is made up largely of water. Water is important for all the activities of protoplasm. It dissolves many types of foods and body wastes. It is needed for the flow of substances into and out of the cells. Most of the chemical reactions taking place in protoplasm are possible only when water is present.

2. Carbohydrates. Carbohydrates are compounds of carbon, hydrogen and oxygen. The ratio of hydrogen and oxygen atoms in a carbohydrate is generally 2:1. Sugars and starches are examples of carbohydrates. Some of the commonly occurring sugars in plant and animal cells are glucose, fructose and sucrose. Sucrose (molecular formula: $C_{12}H_{22}O_{11}$) is synthesized from two smaller sugar molecules, glucose and fructose ($C_6H_{12}O_6$), one molecule of water being lost in the process. Milk contains yet another sugar called lactose which is formed from one glucose and one galactose molecule.

Wheat, corn, potato and tapioca flours are some examples of starches. Most plants store carbohydrates in the protoplasm in the form of starch grains. In the human body there is a special type of starch called glycogen. Starch grains are formed by the condensation and polymerization of a large number of glucose molecules. Another type of carbohydrate is cellulose which forms the walls of plant cells.

Carbohydrates serve as the main source of energy for all living things. In the cells they combine with oxygen to form carbon dioxide and water, releasing a good deal of energy during their oxidation.

3. Fats. Like carbohydrates, fats are also composed of carbon, hydrogen and oxygen but there is a much greater proportion of carbon and hydrogen in a fat molecule than in that of a carbohydrate. Thus the formula of stearin, a common fat, is $C_{57}H_{110}O_6$. Other examples of fats are butter, ghee, vegetable oils and waxes. Chemically, fats and oils are similar, differing only in their physical properties. Fats are solid at room temperature while oils are liquid. In the protoplasm fats are seen as small globules. Weight for weight fats store much more energy than carbohydrates. The seeds of some plants like castor, cotton, groundnut and coconut have large amounts of fats stored in them. Most animals, including man, have a layer of fat beneath the skin.

4. Proteins. Proteins are compounds of carbon, hydrogen, oxygen, nitrogen and usually sulphur. Some proteins also contain phosphorus and atoms of metallic elements such as iron. Their molecules are large and contain thousands of atoms. Proteins are the most important constituents of protoplasm and are indispensable for the building of tissues. Our flesh, hair, skin and nails all consist largely of proteins. The yolk of an egg is mostly protein. In fact no living part of an organism is without proteins.

All proteins are made up of a large number of smaller units called amino acids. Several hundred molecules of amino acids may join to form a protein molecule. Each species of plants and animals has certain proteins which are not found in any other species. In fact that is what makes two human beings different from each other. Not only this, the proteins in one part of a body may be different from those in another part. For example, the proteins in the brain are not the same as those in the muscles of the arm. There are, therefore, millions of different types of proteins. Figure 38.2 will give you an idea of the structure of a protein molecule in three-dimensional view. Now only about 20 types of amino acids have been found to make a protein molecule. One may, therefore, wonder how just 20 amino acids can be used to produce so many different kinds of proteins. But think of the innumerable words that can be written with the 26 letters of the English alphabet. Similarly, the sequence in which the amino acids are put together determines the type of protein formed. The exact sequence of amino acids is known for only a few proteins. One such protein is insulin, a substance which is secreted by the pancreas and which helps in the proper metabolism of sugar in the body. Although the simplest of all known proteins, even this is made up of 51 molecules of amino acids arranged in a particular manner (Fig. 38.3). Professor Sanger of the Cambridge University, England, correctly described the sequence of amino acids in this compound, and was awarded a Nobel Prize in 1958.

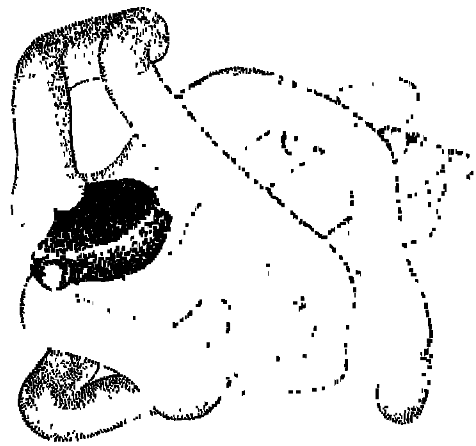

Fig. 38.2. Diagram of a model of myoglobin molecule. The long amino acid chains of this protein are coiled and cross connected. The active part of the molecule is the dark mass—the haeme group. Courtesy of the Department of Botany, University of Delhi.

5. Nucleic acids. Nucleic acids are another kind of organic compounds found in the protoplasm of all living cells. They are so named because they were first recognized in the nucleus. A nucleic acid is made up of five common chemical elements: hydrogen, oxygen, carbon, nitrogen and phosphorus. These elements are combined in different ways to form sugars, phosphates and nitrogen bases. The sugar may be ribose or deoxyribose. The bases are adenine, guanine, cytosine, thymine, and uracil. A single molecule of nucleic acid may contain several thousands of these.

There are two types of nucleic acid—the **ribose nucleic acid (RNA)** and **deoxyribose nucleic acid (DNA)**. RNA occurs

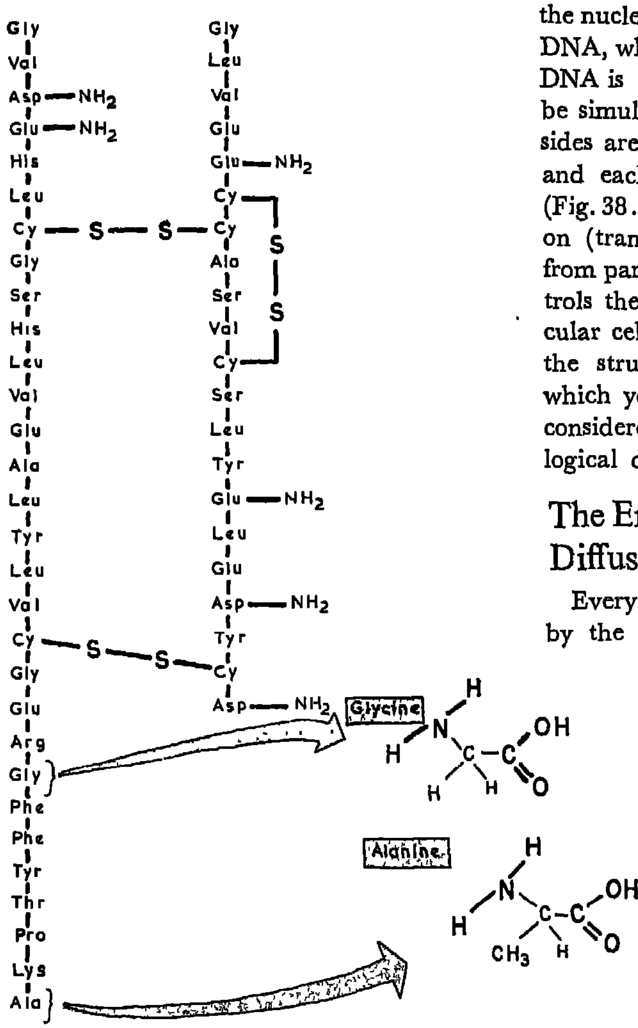

Fig. 38.3. Structure of an insulin molecule. Two of the component amino acids—glycine and alanine—are diagrammed separately. From *BSCS, Biological Science: An Inquiry into Life*, Harcourt, Brace & World, Inc., New York, 1963.

both in the nucleus and in the cytoplasm while DNA is restricted mainly to the nucleus. As the name suggests RNA contains ribose sugar and DNA contains deoxyribose sugar. The three bases, adenine, guanine and cytosine are common to both the nucleic acids. Thymine is present only in DNA, while uracil is present only in RNA. DNA is a double helical structure. It can be simulated to a spiral ladder in which sides are formed of sugar and phosphate, and each stair is formed of a pair of bases (Fig. 38.4). DNA is the substance that passes on (transmits) all hereditary characteristics from parents to their children. It also controls the type of proteins formed in a particular cell through RNA. The knowledge of the structure and function of DNA, about which you will read more in Chapter 52, is considered to be one of the most exciting biological discoveries of the twentieth century.

The Entry and Exit of Materials—Diffusion and Osmosis

Every living cell is bounded on the outside by the plasma membrane which separates it from the outer environment. Therefore, anything that enters or leaves a cell must pass through it. This movement of substances across the plasma membrane occurs by a process known as **diffusion.** You can understand this by a simple experiment. Take a beaker filled with water and gently place in it a crystal of copper sulphate. The blue colour of the crystal gradually spreads to the bottom of the beaker (Fig. 38.5). After a few minutes the colour travels up, and if you leave the beaker for a sufficiently long time the water becomes uniformly coloured. The same is true of a gas. If you open a bottle of perfume in one corner of a room, after sometime its odour spreads all through the room. Although air currents in the room speed up this process, the same result can also be obtained in a closed room. In these experiments copper sulphate and

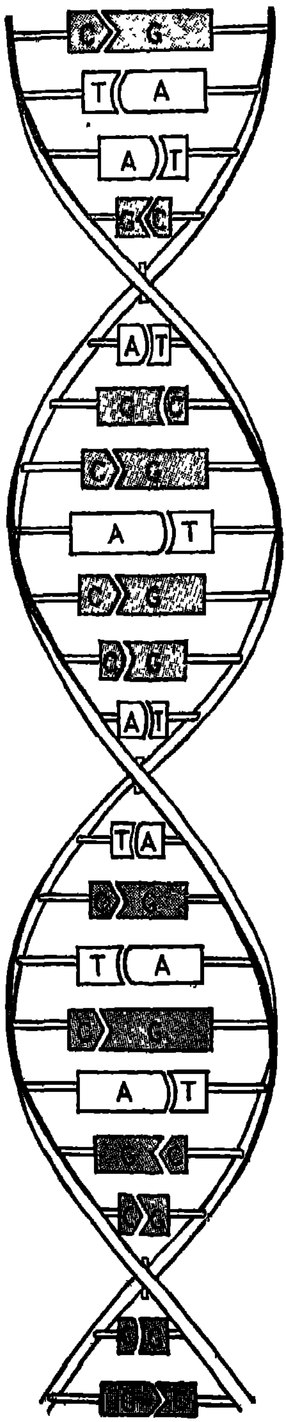

Fig. 38.4. Diagram of the model of a small portion of the DNA molecule. (C stands for cytosine, G for guanine, A for adenine and T for thymine). Courtesy of the Department of Botany, University of Delhi.

perfume are said to have diffused. We can thus define diffusion as the tendency of substances to become equally distributed in the space available to them by moving from the region of their higher concentration to that of lower concentration.

In order to explain this movement we need to know a little of physical chemistry. The molecules of all matter, even of solids, move about in a random way. This movement is much faster in liquids than in solids. In this state of movement the molecules are continuously striking against one another and rebounding. The hotter a substance, the faster is the movement of its molecules. Such collisions are naturally fewer when the number of molecules is small, i.e. when the substance is less concentrated. There is also

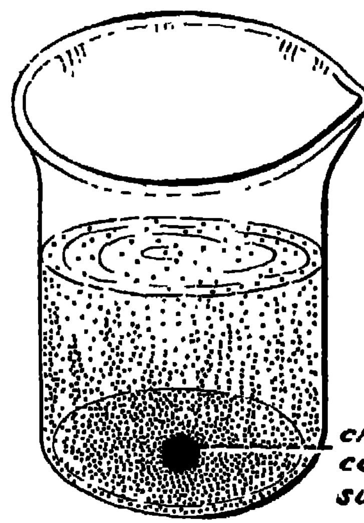

Fig. 38.5., Diagram illustrating diffusion of particles (copper sulphate) through a liquid. Courtesy of the Department of Botany, University of Delhi.

the greatest possibility of their free, unobstructed movement in this area. Because of this continuous movement, the molecules tend to spread themselves out and to become uniformly distributed throughout the available space. Substances diffuse into and out of the cells via the cell membranes. The rate of diffusion through a membrane is of course slower than that in a beaker of water noted before. The plasma membrane is peculiar in that it allows some materials to pass through it more readily than it allows others. In other words it is **semipermeable.** In general, smaller molecules like those of water pass through it more readily than larger molecules like those of sugar. This suggests that there are small pores in the membrane which restrict the passage of larger particles. The membrane is made mainly of proteins and fats. Substances which can dissolve in the fat can pass through the membrane even if they have a large molecular weight. Another unique property of the plasma membrane is that its permeability may change under certain conditions. This means that it may allow certain substances to pass through it at one time but may prevent the passage of the same substances at other times. This property of controlling the passage of substances helps to preserve the proper chemical composition of the cell. In addition to the plasma membranes, plant cells also have cellulose walls. In these the pores are large and offer no hindrance to the flow of dissolved substances. Cellulose walls are, therefore, said to be fully permeable. The property of semipermeability is characteristic of living membranes only. When a cell dies, its membrane becomes fully permeable. You can verify this by a simple experiment. Take two thin slices of tissue from a red beet root and wash them several times with water. Now place one slice in a test tube containing tap water and immerse the other in boiling water for five minutes. The latter treatment kills all the cells. Put the killed slice into another test tube containing tap water. After a few hours it will be seen that whereas the red colour has freely diffused out of the second slice, in the first it is still retained in the cells. The escape of colour from the second slice results from the loss of permeability of the membranes when the cells are killed.

Let us now see how things reach the cells by diffusion. As already mentioned the cell membrane will normally allow only substances of low molecular weight to pass through. How is it then, that such large particles as starch grains and protein molecules get into the cells? Let us consider the cells of our skin. We know that the lower layers of the skin are constantly producing new cells. In order to trace the origin of new protoplasm in these cells we have to go back to the food we eat. This consists of many kinds of substances such as starch, fats and proteins which are insoluble in water. These substances are broken down (digested) in the alimentary canal into simpler, soluble substances. For instance, the proteins are broken down to amino acids, starch is converted into sugars, fats into glycerol and fatty acids, and so on. The concentration of the soluble substances in the intestine becomes high and, therefore, they diffuse into the cells of the intestinal wall. These are in close contact with the blood vessels. Since the dissolved particles of food are now more numerous in the intestinal cells than in the blood, they diffuse into it. The blood enriched with food materials now moves to different parts of the body where the cells normally have less food. The cell membranes in contact with the blood vessels receive food from the blood by diffusion and in turn supply some of this food to their neighbouring cells which are not in direct

contact with the blood capillaries. In this way food moves from cell to cell. After entering the cell these soluble food materials are again converted into the complex compounds of the protoplasm. This is how the protoplasm in our skin cells is built from substances diffusing into it from the food that we eat.

Let us examine another familiar case. We have learnt that during daytime plants take in carbon dioxide and liberate oxygen. This again results from diffusion. The carbon dioxide which is present in the air spaces of the leaves is being constantly utilized by the green cells to prepare food materials. This results in a decrease in the carbon dioxide concentration in the leaf. More carbon dioxide, therefore, diffuses into it from outside. At the same time oxygen given out by the green cells becomes more abundant in the air spaces than in the outer atmosphere and diffuses out through the stomata. These two examples will serve to demonstrate the important role played by diffusion in the life of a cell. Diffusion of one substance does not affect the diffusion of another. Thus several substances may be diffusing into and out of a cell at the same time.

The diffusion of water through a semipermeable membrane occurs in the same way as that of any other dissolved substance, but it needs some further consideration. You can perform a simple experiment to understand it. Take a thistle funnel and tie a piece of goat's bladder over its mouth. This membrane is semipermeable; water molecules can pass through it but not those of cane sugar. Fill the thistle funnel to half the length of its stem with a concentrated solution of cane-sugar. Invert the funnel in a beaker containing pure water. After some time it will be noticed that the level of the sugar solution rises in the stem (Fig. 38.6). Since the membrane is permeable only to water and since there are more water molecules in the beaker than in the funnel, there is a net movement of water into the funnel and a rise in the level of the solution in it. This diffusion of water through a semipermeable membrane is termed **osmosis.**

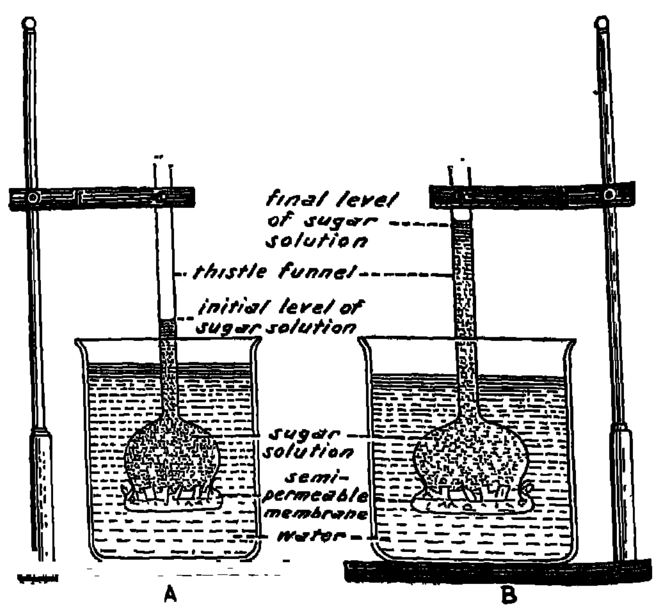

Fig. 38.6. Demonstration of the phenomenon of osmosis. The semipermeable membrane holds back sugar molecules but permits free movement of water molecules. A. Apparatus at the commencement of the experiment. B. After a few hours; note the rise in the level of the solution. Courtesy of the Department of Botany, University of Delhi.

Cells, however, often show a behaviour which cannot be explained by the phenomenon of osmosis or of diffusion. For instance, the cells of seaweeds accumulate iodine in much higher concentration than is present in the sea water. Similarly the leaves and roots of sugarcane have very little sugar in them, whereas the cells in the stem accumulate large quantities of sugars. Such movement of materials against diffusion gradient is possible only by expenditure of energy. The energy is spent first in absorbing the substance against the concentration gradient, and secondly in preventing its escape from the cell.

Several important medical practices are based on our knowledge of the role of osmosis in the life of a cell. For instance, plain water is never injected into the body because the red blood cells would absorb this water greedily and burst. Some of you might have experienced an irritation when you happened to 'drink' water through your nose. This results from the absorption of water by the cells of the mucous membrane lining your nose. When your foot is sprained and swollen, the doctor often advises you to soak it in hot water containing a large amount of common salt. Since the concentration of water in this solution is less than that in the cells of your foot, water from the cells would pass out by osmosis. The removal of water would reduce the swelling. On the same principle, when a medicine is injected into the human body, it is made in 0.87 per cent salt solution. This is approximately the concentration of the dissolved matter in our red blood cells. You might also have experienced that if you keep your hand immersed in water for a long time, it becomes soft and swollen. This is due to the entry of water into the cells by osmosis. On the other hand, if you were to soak yourself in sea water for a long period, your body would shrink. Sea water has a high concentration of salt (3.5 per cent) and draws out water from the cells by osmosis.

If cells are suspended in a solution which has the same concentration of the solute as the cytoplasm (isotonic), they retain their shape since there is no gain or loss of water. If the concentration of the outer solution is higher (hypertonic) the cells lose water and their cytoplasm shrinks. This phenomenon is known as **plasmolysis** (Fig. 38.7). The shrinkage or plasmolysis is proportional to the concentration of the outer solution. If it is too severe, it is often fatal to a cell. When the cells are suspended in a solution in which the concentration of the solutes is less than in the cytoplasm (hypotonic), the cells absorb a lot of water and become greatly extended or turgid. You can perhaps now appreciate why jams can keep free from moulds and bacteria. When mould spores or bacteria fall on to the highly concentrated sugar solution of the jam, they become badly plasmolysed. Devoid of water, the spores fail to germinate, and the bacteria are unable to multiply.

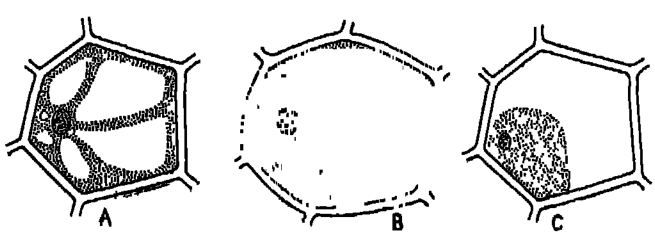

Fig. 38.7. Behaviour of plant cells in isotonic(A), hypotonic (B) and hypertonic (C) solutions (*see* explanation in text). Courtesy of the Department of Botany, University of Delhi.

Provision of Energy

One of the basic differences between the living and the non-living is that the living organism demands a continuous supply of energy as long as it is alive. It needs energy to run the life processes such as synthesis of new chemical substances, growth, movement, reproduction, maintenance of body temperature and so on. Even when all of the visible life activities like movement, intake of food, and reproduction are suspended, there is some expenditure of energy to stay alive. Unlike a motor car the living organism cannot be parked by the roadside with its engine switched off. The organism must keep its 'engine' working all the time, or else it dies.

Wherefrom does this energy come? Let us first look for its source in the body of an animal, say man. You must have often noticed that a person going on a fast becomes weak and inactive. If the period of fast is prolonged, even death may occur. We can, therefore, conclude that the energy to do work or to remain active comes from the food we eat.

Let us go a little deeper into this problem. Energy may be defined as the capacity for doing work. Work is done when atoms are bonded together into molecules; the energy in this process is stored in the bonds and can be released when the bonds are broken. The energy from the food is obtained by breaking the bonds of the molecules contained in the substances of the food. Although all sorts of compounds can be broken down in a cell to release energy, glucose is the one which is most commonly used. The energy contained in the bonds between two carbon atoms or between an atom of carbon and another of hydrogen is not released in one leap but in several steps. The carbon atoms in the molecule are set free one by one. They combine with oxygen to form carbon dioxide. The hydrogen atoms are released in pairs. They too combine with oxygen and form water. You know that oxygen is essential for respiration. You can now understand how oxygen is used in the cell.

One more aspect of energy in the cell must be considered. The energy released from the chemical bonds is like a bank cheque which must be changed into currency in order to use it. This energy currency of the cell is in the form of a substance called **adenosine triphosphate** or **ATP**. ATP is made of a adenosine combined with three phosphate groups (Fig. 38.8). The bonds between the phosphate groups are rich in energy. A considerable amount of energy is spent in their formation, and about the same is released when these bonds are broken. The energy released from the oxidation of glucose or other foods is used to add one phosphate radical to another substance—**adenosine diphosphate** or **ADP**—in order to convert

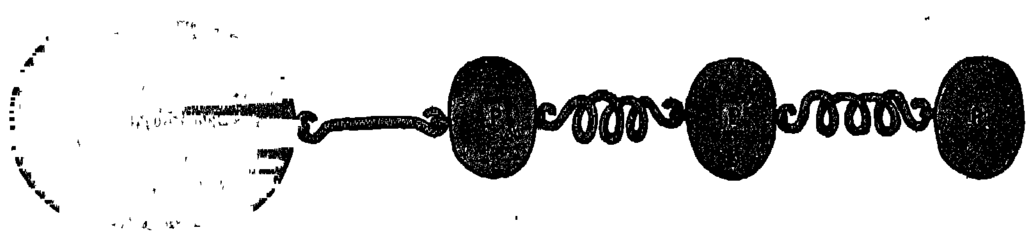

Fig. 38.8. Diagrammatic representation of an ATP molecule. Courtesy of the Department of Botany, University of Delhi.

it into ATP. You will read more about this in Chapter 42. The cycle of formation of ATP from ADP by the breakdown of food materials continues in all living cells at all times.

Enzymes

A wholesome meal consisting of proteins, fats and starch becomes digested (changed into soluble form) in our bodies within a few hours. The same materials kept in the test tube do not change at all or do so very slowly unless they are treated with strong acids or alkalies at high temperature and pressure. The body achieves the required changes at ordinary temperature and without any strong acid or alkali. This is made possible by special substances called **enzymes** present in the cell. These act like catalysts. As you have already read in your chemistry class, catalysts are agents which speed up a chemical reaction without undergoing changes themselves. They are used in industry to promote certain chemical reactions. For instance, finely divided platinum is used in the industrial manufacture of sulphuric acid. Catalysts inside the cells are concerned with life activities, and are therefore known as biocatalysts or enzymes. Each cell in the body contains a large number of enzymes to bring about all the chemical changes that are going on all the time. A given enzyme catalyzes only a particular type of reaction, i.e. *it is specific* in its action. The enzyme amylase, for instance, can break down starch but nothing else. Enzymes also do their jobs best at a particular temperature (generally between 25 and 37 C).

Consider a single tiny cell carrying on hundreds of chemical reactions. In the limited space it could hold only a minute quantity of each type of enzyme. Obviously a very small amount of each enzyme meets the needs of a cell. We are naturally led to ask: How does an enzyme act? It is believed that the complex molecule of an enzyme has certain points on its surface at which the reacting molecules attach themselves (Fig. 38.9)— an arrangement which simulates the fitting of a key to a lock. As only a particular key can properly fit into a lock, in the same way only a particular enzyme can fit with a particular substrate to be able to act on it.

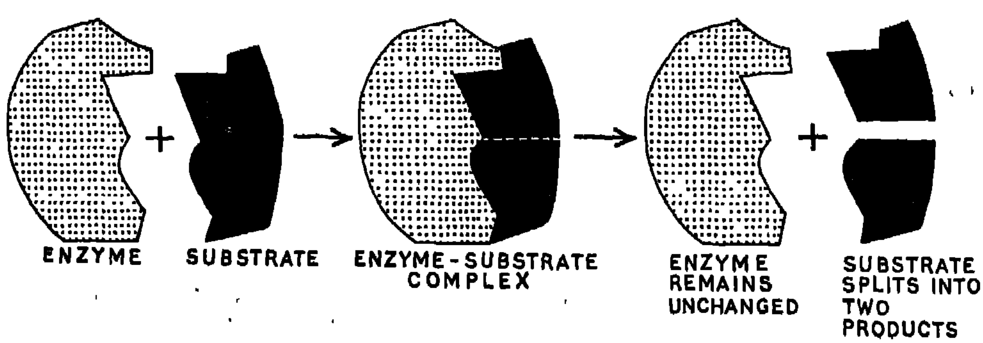

Fig. 38.9. Diagrammatic representation of an enzyme-substrate reaction. According to this concept, the enzyme is geometrically specific for this particular substrate, and the substrate molecule is split into two product molecules. The enzyme remains unchanged at the end, and may serve over and over in such reactions. Courtesy of the Department of Botany, University of Delhi.

All enzymes are proteinaceous in nature and contain a large number of atoms in each molecule. Sometimes the enzyme molecule also has a small non-protein part. The latter may be just an atom of some metal, such as iron or zinc, or a more complex organic compound. You have often noted the doctor recommending the use of vitamins to his patients. The vitamins are actually parts of certain enzymes in the body. If the body is deficient in vitamins, the enzymes do not work properly and the patient suffers from various disorders.

SUMMARY

The cell is the smallest unit of an organism that exhibits all the properties of life. In many ways a cell is comparable to a factory.

The protoplasm contains the same chemical elements as those found in many non-living objects. Carbon, hydrogen, oxygen and nitrogen make up as much as 99 per cent of the bulk. These elements occur chiefly in the form of compounds. The most common are water, carbohydrates, proteins, fats, nucleic acids and mineral salts. All cells live in a moist environment. The dissolved substances enter the cells by diffusion, a process in which the movement of a substance always occurs from a region of higher to a region of lower concentration.

Water is absorbed by osmosis. Osmosis is the diffusion of water through a semipermeable membrane from a region of its higher concentration to a region of its lower concentration.

The energy for the various life processes comes from the oxidation of foods in the cell. Two compounds, ATP and ADP, form the cell's energy currency.

Each cell is a seat of many chemical reactions. These are promoted by minute quantities of organic catalysts called enzymes.

QUESTIONS

1. What is the difference between diffusion and osmosis?
2. Common salt is often sprinkled on weeds in order to eliminate them from playgrounds. Explain why this practice is effective.
3. Which of the following elements is most abundant and which one is least abundant in the protoplasm of an active cell: (a) carbon, (b) oxygen, (c) hydrogen, (d) phosphorus, (e) nitrogen, (f) potassium.

4. Explain the following:

   (a) Meat sprinkled with salt remains free from moulds and bacteria for a long time.

   (b) A marine animal bursts if kept in freshwater.

   (c) If the fields are fertilized too heavily, there are chances of obtaining a lower yield instead of a higher yield.

   (d) Plants may sometimes wilt even when the field is thoroughly watered.

5. Make diagrams of normal and plasmolysed cells.

6. The hyphae of moulds are soft and delicate structures. How can they penetrate such hard objects as woods?

7. Name three properties common to all enzymes.

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CHAPTER 39

Autotrophic Nutrition

LIVING organisms must have food in order to build their bodies and to derive energy for the various life activities. The basic food requirements of animals as well as plants are the same, namely, proteins, carbohydrates, fats and mineral substances. However, green plants are unique among organisms in that they can prepare most of their food from simple substances, mostly water and carbon dioxide. They produce food not only for themselves but also for the non-green plants and all the animals including man. The process by which this is done is known as **photosynthesis** or 'putting together with the help of light'. Essentially it is a process in which the energy of sunlight is captured and used in the formation of carbohydrates from carbon dioxide and water.

The materials composing the bodies of all living organisms are derived from the products of photosynthesis. The energy for all life activities can be traced back to that bound during the process of photosynthesis. It is mainly because of this process that the oxygen content of the earth's atmosphere is kept constant. Although we are now learning to utilize atomic energy for certain industries, we are still largely dependent upon photosynthesis for most of our requirements of energy.

Organisms such as green plants, which can manufacture their own food material from simple substances, are called **autotrophs.** Others, such as animals and the non-green plants which cannot make their own food, are termed **heterotrophs.**

Development of the Knowledge of Photosynthesis

The knowledge that plants possess the ability to produce their own food was acquired after long speculation and experimentation. The story of this revelation is one of the most exciting chapters in the history of biology.

Until the beginning of the 17th century most people believed that plants 'suck' their food from the soil through the roots. In the year 1648 van Helmont, a Belgian scientist, thought of testing this idea experimentally. He took a young willow twig and planted it in a barrel containing a weighed amount of soil. He fed this twig with rain water only. After five years the twig had grown to a small tree, and had gained 74.3 kg in weight (Fig. 39.1). There was a slight decrease (56.7 g) in the weight of the soil but no importance was attached to it. He concluded that the food of plants is derived from water, and that the wood,

Fig. 39.1. Van Helmont's experiment with willow twig. From E.E. Bayles and R.W. Burnett, *Biology for Better Living*, Silver Burdett Company, New York, 1946.

bark, roots and leaves all come from just water. As we shall soon see, however, van Helmont was only partially right in this supposition.

The first real clue to photosynthesis was given in 1772 by an English scientist named Joseph Priestley. He was primarily concerned with the study of gases given out during combustion and during breathing by animals. In one of his experiments he observed that a mouse kept under a bell jar soon died of suffocation because the air became 'impure' as a result of breathing. Priestley inferred that there must be some mechanism in Nature by which the 'spoiled' air of the atmosphere is re-purified. He suspected that plants were concerned in this process in some way. He placed twigs of plants under bell jars containing impure air, and discovered that plants did really purify it. Next, he confined two mice under two airtight bell jars. In one of them he also kept a twig of mint (Fig. 39.2). And can you imagine what he found? The mouse shut up in the bell jar with the mint twig was hale and hearty while that in the other jar died of suffocation. Thus, it was clear that plants could purify air and made it possible for animals to live in it.

Priestley failed to realize that such purification of impure air could be achieved only in light and by the green parts of a plant. These facts were brought out around 1773 by the investigations of a Dutch physician, John Ingen-Housz. He demonstrated that at night plants also spoil the air just as animals do.

Neither Priestley nor Ingen-Housz knew the chemical identity of the pure and impure air and it was left for Antoine Lavoisier, a French chemist, to discover that the impure air contained much carbon dioxide, that in sunshine green plants fix the carbon, and that oxygen is given out as a waste product

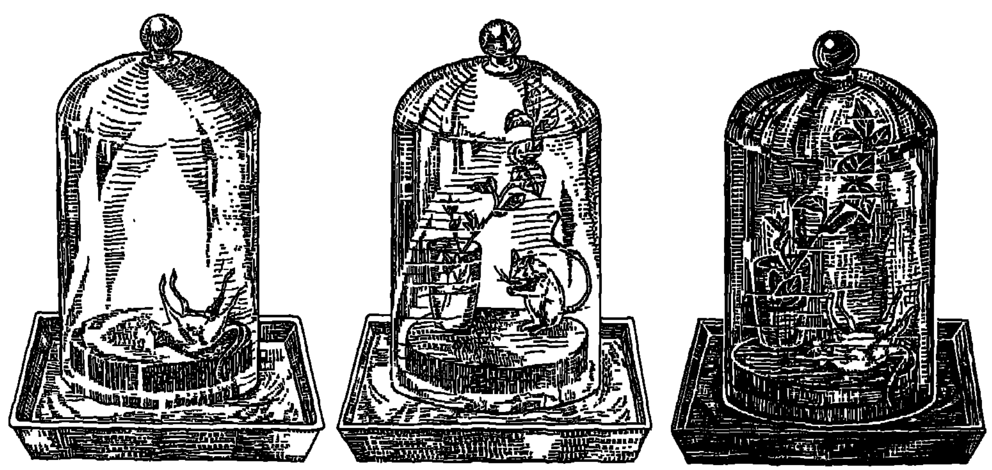


Fig. 39.2. Experiments of Priestley and Ingen-Housz. A. A mouse kept alone inside a bell jar soon dies because it exhausts the oxygen in the jar. B. When a plant is kept along with the mouse, the oxygen produced by photosynthesis keeps the mouse alive. C. At night, in spite of the presence of the plant, the mouse dies because of scarcity of oxygen as the plant does not continue to produce oxygen at night (this experiment was, however, not done by Priestley). After W.G Whaley, O.P. Breland, C. Heimsch, Austin Phelps and A.R. Schrank, *Principles of Biology*, Harper & Brothers, Publishers, New York, 1958.

of photosynthesis. Thus, as a result of nearly 150 years of experimentation, we came to understand that green plants have the unique capability to combine two simple substances, carbon dioxide and water, into glucose from which are derived all the other products of plants as well as animals.

The state of our understanding of photosynthesis at the beginning of the present century could be summarized as follows:

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \xrightarrow[\text{chloroplasts}]{\text{light}} \underset{\text{carbohydrate}}{(CH_2O)_n} + \underset{\text{oxygen}}{O_2}$$

It should be noted, however, that this equation is only a brief statement of the input and output. It fails to bring out several important aspects of the process. For example, carbohydrates are not formed simply by mixing carbon dioxide and water. Indeed, if you try mixing these two substances in the ordinary way, you will get only carbonic acid.

Mechanism of Photosynthesis

How do plants entrap the energy of the sun and convert it into chemical energy? If we could understand all the steps, we should be able to duplicate them in the test tube, and become independent of plants with regard to our supply of food and oxygen. Due to the continuous efforts of biologists, chemists and physicists we have no doubt gone quite far in our knowledge of the subject, but its complete understanding is not yet in sight. The process of photosynthesis actually involves a large number of reactions. We shall consider only some basic aspects of this in a greatly simplified manner.

When sunlight falls on the green tissue of a leaf, the chlorophyll absorbs the light energy and this energy is used to split water into hydrogen and oxygen. The oxygen is given out while the hydrogen atoms combine with carbon dioxide to form a sugar-like compound with three carbon atoms in the molecule. Finally, two molecules of the 3-carbon compound unite and form glucose which has six carbon atoms in a molecule. The overall summary equation may be written as:

$$\underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} \xrightarrow{\text{chloroplast}} \underset{\text{glucose (sugar)}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2}$$

It has been found that light plays its role only in the first stage, i.e. in the splitting of water into free oxygen and hydrogen. The other reactions go on just as well in the light as in the dark (Fig. 39.3).

The summary equation does not indicate whether the released oxygen comes from carbon dioxide or from water. Indeed, when biologists first studied this process, they had no way of knowing the exact source of oxygen. Later it became possible to answer this question by the use of specially prepared water containing oxygen with an atomic weight of 18 instead of 16. Although chemically similar to normal oxygen (O^{16}), the heavy oxygen (O^{18}) can be detected by a special instrument. Thus, when plants were supplied with water containing this isotopic oxygen (H_2O^{18}), the released oxygen was entirely of the O^{18} type, indicating that water was the source of oxygen released during photosynthesis. Our summary equation will, therefore, be more correct if we write it as follows:

$$6CO_2+12H_2O^{18} \longrightarrow C_6H_{12}O_6+6H_2O+6O_2^{18}$$

Another function of light energy in this process is the formation of ATP through a series of chemical reactions.

The sugar produced in this process is glucose. The veins remove it from the leaf cells to other parts of the plant. When the

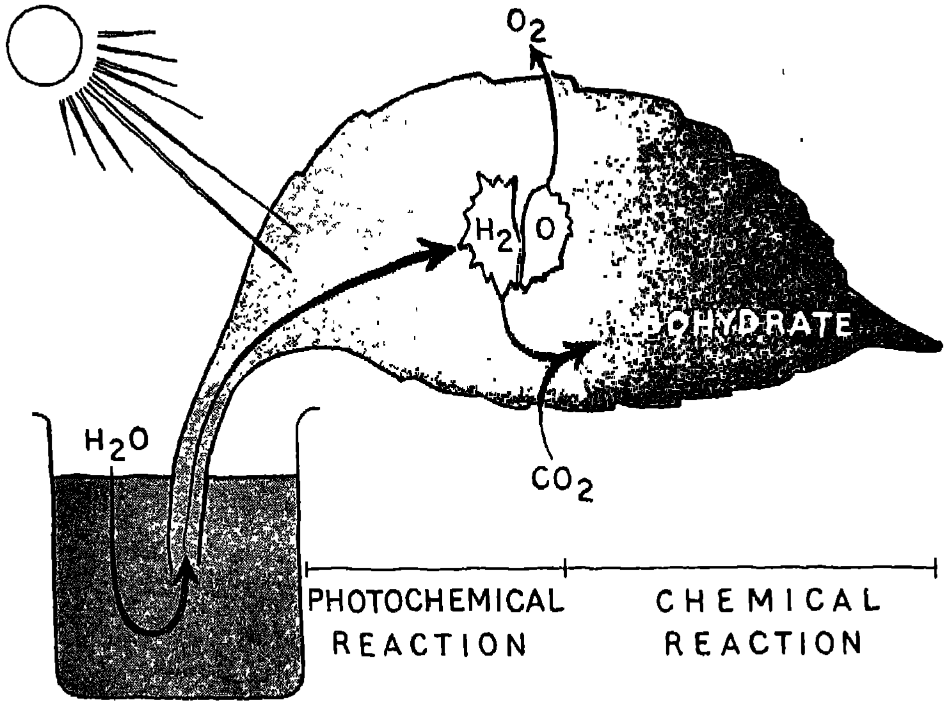


Fig. 39.3. Diagram showing photochemical and chemical phases of photosynthesis. Courtesy of the Department of Botany, University of Delhi.

rate of photosynthesis is very high, the conducting system cannot remove the sugar as fast as it is synthesized. If sugars were to accumulate at the place of their synthesis, i.e. in the chloroplasts, there would be a 'blocking in the factories'. The rate of photosynthesis would then fall. However, the extra glucose is converted into an insoluble carbohydrate, namely, starch, so that the work of the chloroplasts is not impeded.

If the white light of the sun is split into its component colours by means of a large prism, and the leaves are allowed to photosynthesize separately in each of these colours, it is seen that maximum photosynthesis occurs in the red and blue regions. This is because chlorophyll can absorb only these two colours effectively (Fig. 39.4).

Leaves—the Food Factories

The leaf is an organ specially suited to carry on photosynthesis. The expanded leaf blade presents a large surface to receive light. You have read in Chapter 13 that the leaf epidermis contains many minute openings called stomata. They open during daytime when the guard cells are fully turgid, and close when these cells lose turgidity (Fig. 39.5). In the dark when photosynthesis does not take place they contain mostly starch which being insoluble in water is osmotically inactive. So the guard cells become flaccid and the stomata close. During the day due to photosynthesis soluble sugars accumulate in guard cells. This increased concentration results in a greater absorption of water and the

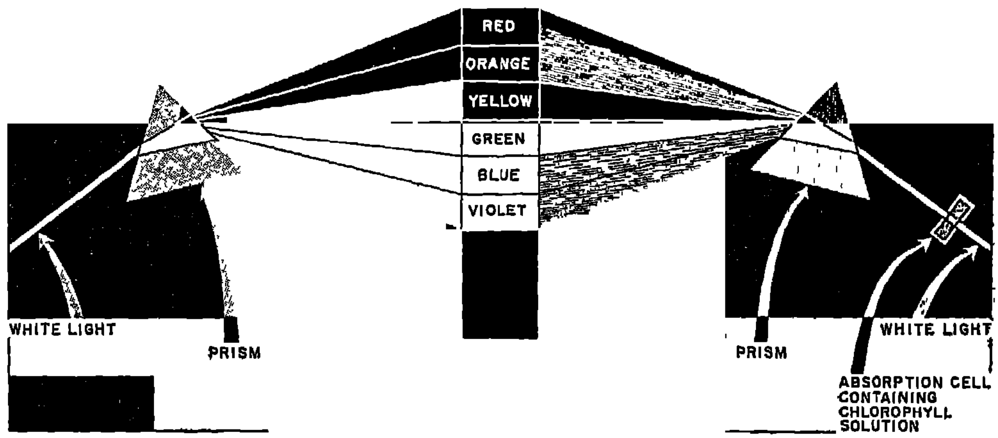


Fig. 39.4. Absorption spectrum of chlorophyll. When a beam of white light is passed through a chlorophyll solution (right) there is strong absorption in the violet-blue and orange-red regions (shaded areas). The indigo band has not been shown. From *BSCS, Biological Science: An Inquiry into Life,* Harcourt, Brace & World, Inc., New York, 1963.

opening of the stomata (Fig. 39.5). The leaf is provided with conducting tissue which enables a two-way transport. The xylem elements bring water and mineral salts to the leaves while the phloem elements carry away the carbohydrates to the other parts. The internal structure of the leaf, as you will recall from Chapter 13, is also suited to do the job most effectively. The cells of the palisade and spongy layers are the work-rooms; the chloroplasts with their packing of chlorophyll and enzymes are the machines; the power to run the 'leaf factory' comes from sunlight; carbon dioxide (entering through the stomata) and water (coming through the xylem in the veins) are the raw materials; glucose is the chief product; and oxygen is a 'waste' gas given out into the atmosphere. The manufacturing department of the leaf factory works only during daytime whereas the transportation and supply departments work day and night.

Plants and Gaseous Exchange

Since green plants give out oxygen during the day, an erroneous belief sometimes exists among people that plants carry on photosynthesis during the day, and respiration at night. An explanation of the gaseous exchange between the plants and the atmosphere is, therefore, necessary at this stage. Actually plants respire all the time—day and night—taking in oxygen and giving out carbon dioxide. However, during the day photosynthesis also occurs. In this process carbon dioxide is used up and oxygen is given out, whereas in respiration oxygen is utilized and carbon dioxide is given out. Now it happens that the process of photosynthesis proceeds at a much faster rate than respiration. The carbon dioxide produced in respiration is used up in the photosynthesizing tissues as soon as it is formed. Besides, additional carbon dioxide diffuses in from the atmosphere to maintain photosynthesis at a steady rate. The oxygen released in photosynthesis is far in excess of that required in respiration, so the unused oxygen escapes into the atmosphere (Fig. 39.6). The overall outcome of these two simultaneous processes is that during the day the plants give out oxygen and take in carbon

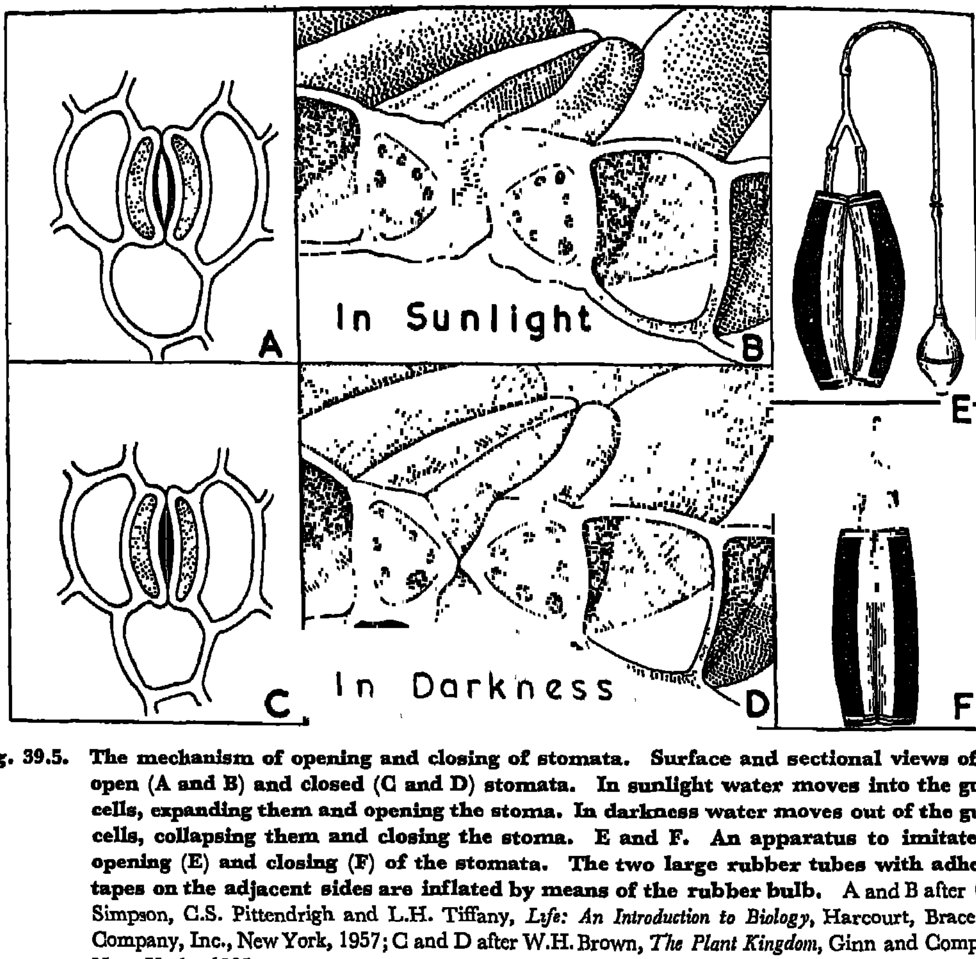


Fig. 39.5. The mechanism of opening and closing of stomata. Surface and sectional views of the open (A and B) and closed (C and D) stomata. In sunlight water moves into the guard cells, expanding them and opening the stoma. In darkness water moves out of the guard cells, collapsing them and closing the stoma. E and F. An apparatus to imitate the opening (E) and closing (F) of the stomata. The two large rubber tubes with adhesive tapes on the adjacent sides are inflated by means of the rubber bulb. A and B after G.G. Simpson, C.S. Pittendrigh and L.H. Tiffany, *Life: An Introduction to Biology*, Harcourt, Brace and Company, Inc., New York, 1957; C and D after W.H. Brown, *The Plant Kingdom*, Ginn and Company, New York, 1935.

dioxide. In the night photosynthesis stops but respiration continues, and we find the reverse type of gaseous exchange, namely, the release of carbon dioxide and taking in of oxygen (Fig. 39.7). The characteristic gaseous exchange of plants is, therefore, due to the masking of the respiratory process by photosynthesis during the day.

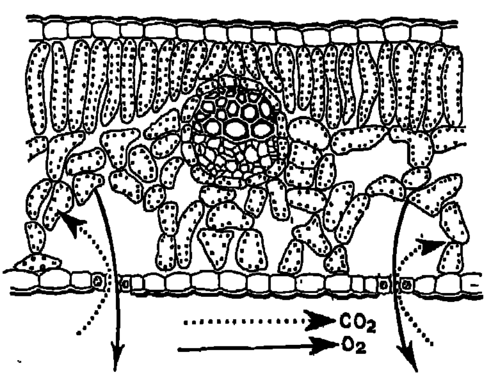


Fig. 39.6. Cross section of a leaf showing the movement of carbon dioxide and oxygen during the day. How would the direction of movement of the gases change at night? From *BSCS, Biological Science: An Inquiry into Life*, Harcourt, Brace & World, Inc., New York, 1963.

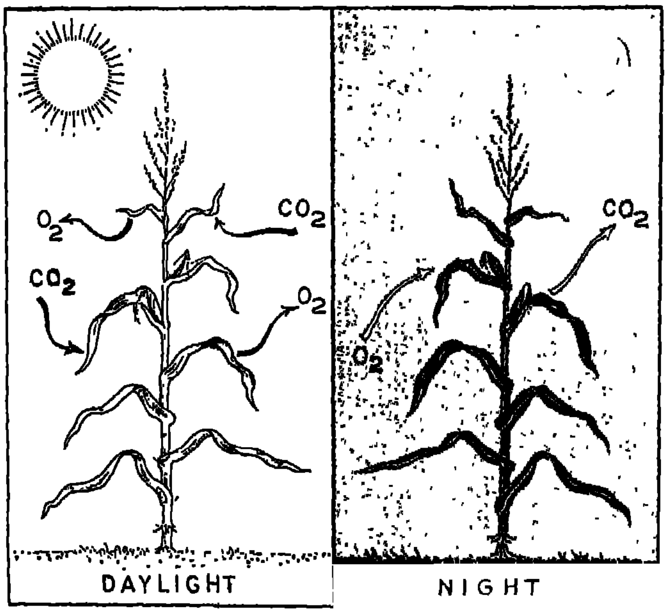


Fig. 39.7. Relationship between light and the gases given off from plants. During daylight a plant produces more oxygen in photosynthesis than it uses in respiration; hence there is an excess of oxygen which is given off from the leaves. As night falls, photosynthesis stops and the carbon dioxide produced in respiration is given off from the leaves. After A.M. Winchester, *Biology and Its Relation to Mankind*, D. Van Nostrand Company, Inc., Princeton New Jersey, 1964.

Studying Photosynthesis in the Laboratory

You can perform a number of simple experiments to show that plants make food only under certain conditions.

Let us first determine if chlorophyll is necessary for this process. Cut a variegated leaf of *Coleus* or *Manihot* from a plant which has been exposed for several hours to bright sunlight. Trace the outline of the leaf, and the boundary between the green and the variegated portions. Now kill it by immersion in boiling water, and then drop it in hot methylated spirit. The spirit will dissolve out the chlorophyll. Wash the leaf with water and keep it under a solution of iodine. Iodine has the property of colouring starch blue-black. It will be seen that only the green parts of the leaf show the presence of starch (Fig. 39.8).

A simple experiment may be performed to show that plants give out oxygen during the day. Since oxygen is easily collected over water, a water plant like *Hydrilla* is good for this experiment. Put a few twigs of this in a beaker of water and keep it in the sun. Bubbles of gas start coming out of the cut ends of the twigs. Enclose the twigs in a funnel and invert over its stem a test tube full of water (Fig. 39.9). The gas will now collect in the tube by a downward displacement of water. The gas collected in the tube gives the glowing splinter test for oxygen.

The necessity of light for photosynthesis can also be demonstrated by this experiment. *Hydrilla* would stop bubbling in darkness and would give out only a few bubbles in dim light.

The requirement of carbon dioxide for photosynthesis can be demonstrated by the so-called half-leaf experiment. Take a long-leaved potted plant and keep it in the dark for a couple of days so that photosynthesis stops completely, and the leaves become free of starch. Enclose one half of a leaf in a

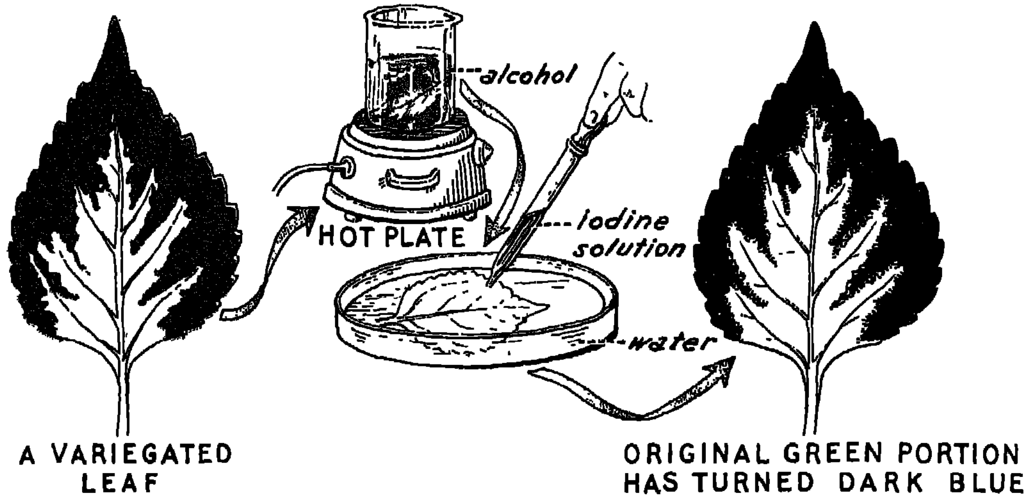
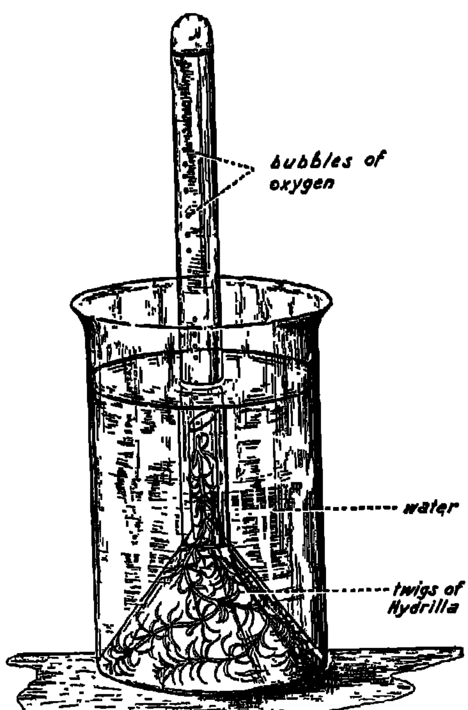


Fig. 39.8. Experiments to demonstrate that chlorophyll is necessary for photosynthesis. A killed variegated leaf is put in hot alcohol to dissolve out the chlorophyll. It is then washed in water and bathed in iodine solution. The originaly green portion turns dark-blue. Courtesy of the Department of Botany, University of Delhi.



bottle containing a strong solution of potassium hydroxide as shown in Fig. 39.10. The potassium hydroxide absorbs carbon dioxide making it unavailable for the enclosed part of the leaf, while the exposed part receives it from the atmosphere. If you test the leaf for starch after some time you will find that whereas the part of the leaf outside the bottle shows the presence of starch, the enclosed half is without it. The enclosed part did not photosynthesize due to the non-availability of carbon dioxide.

We have seen that light, water and carbon dioxide are the three important external factors influencing the rate of photosynthesis. Usually light and water are abundant, but the supply of carbon dioxide is limited because of its low percentage (0.03) in the air. Under such conditions the rate of the photosynthetic process is limited by the low

Fig. 39.9. Experiment to demonstrate the release of oxygen during photosynthesis. Courtesy of the Department of Botany, University of Delhi.

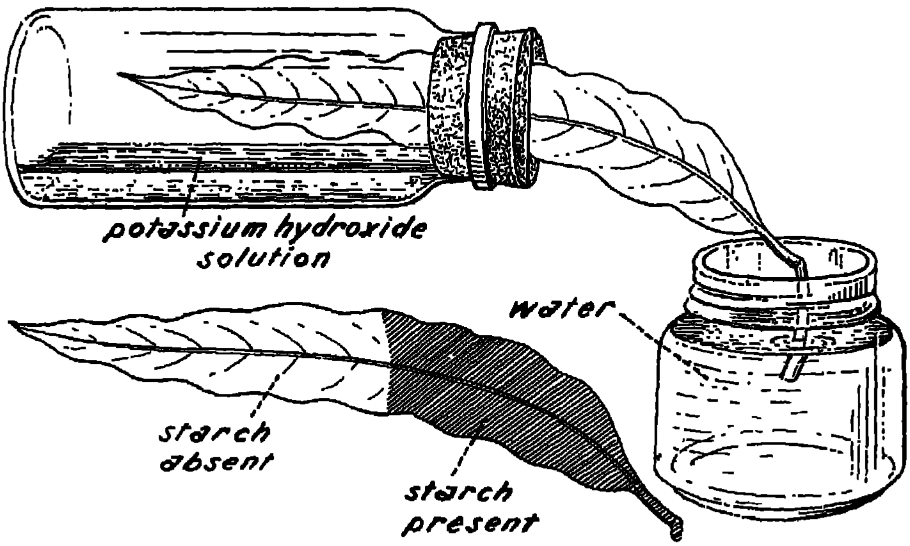


Fig. 39.10. Experiment to demonstrate that carbon dioxide is necessary for photosynthesis (Moll's half-leaf test). Courtesy of the Department of Botany, University of Delhi.

concentration of this gas. In this context carbon dioxide is a 'limiting factor', i.e. one which limits the speed of a process. Increasing the quantity of carbon dioxide should, therefore, result in increased photosynthetic activity and consequently better yields. It has actually been demonstrated that increasing the concentration of carbon dioxide in the air around the plants by means of gas pipes from factories results in better yields of certain field crops.

Chemosynthesis

In the beginning of this chapter we made a general statement that only green plants are autotrophic. We shall now note some exceptions to this generalization. There are certain bacteria which lack chlorophyll but still have the ability to combine carbon dioxide and water into carbohydrates. Being devoid of chlorophyll, they cannot utilize the energy of the sun for this process. Instead, they oxidize certain natural inorganic substances, and the energy generated in these oxidations is used by them to make their food from carbon dioxide and water. Thus, these bacteria utilize chemical energy in place of light energy. They carry on chemosynthesis instead of photosynthesis. In other words, they are chemosynthetic autotrophs. Several types of chemosynthetic bacteria are known in Nature. They are named according to the substances oxidized by them. The hydrogen bacteria oxidize hydrogen to water:

$$2\,H_2 + O_2 \xrightarrow[\text{Hydrogen bacteria}]{} 2\,H_2O + \text{energy}$$

The sulphur bacteria oxidize hydrogen sulphide gas into free sulphur and water:

$$2\,H_2S + O_2 \xrightarrow[\text{Sulphur bacteria}]{} 2\,S + 2H_2O + \text{energy}$$

The iron bacteria bring about the oxidation of iron compounds:

$$4\,FeCO_3 + O_2 + 6H_2O \xrightarrow[\text{Iron bacteria}]{} 4Fe(OH)_3 + 4CO_2 + \text{energy}$$

It is believed that the huge deposits of sulphur and iron ores found in the earth have resulted from the activities of these bacteria.

The Carbon Cycle

It has been estimated that the green plants of the earth utilize some 690 billion tons of carbon dioxide per year in the process of photosynthesis. The concentration of carbon dioxide in the atmosphere is 0.03 per cent, amounting to about 2,200 billion tons. With the continuation of photosynthesis, the carbon dioxide would eventually be exhausted. However, the concentration is actually maintained at the same level. The major processes by which the carbon returns to the atmosphere are the respiration of plants and animals, and the decay of animal excreta and dead bodies caused by bacteria and fungi. A certain amount of carbon remains locked up in the ground for long periods—as when the remains of plants and animals are incompletely decayed and changed into coal and petroleum. Sooner or later these are also burnt by man. Thus, the carbon which once entered from the atmosphere into the green plant again becomes a part of the inorganic world. The vaiious changes concerned with this circulation of carbon are said to form the **carbon cycle** (Fig. 39.11).

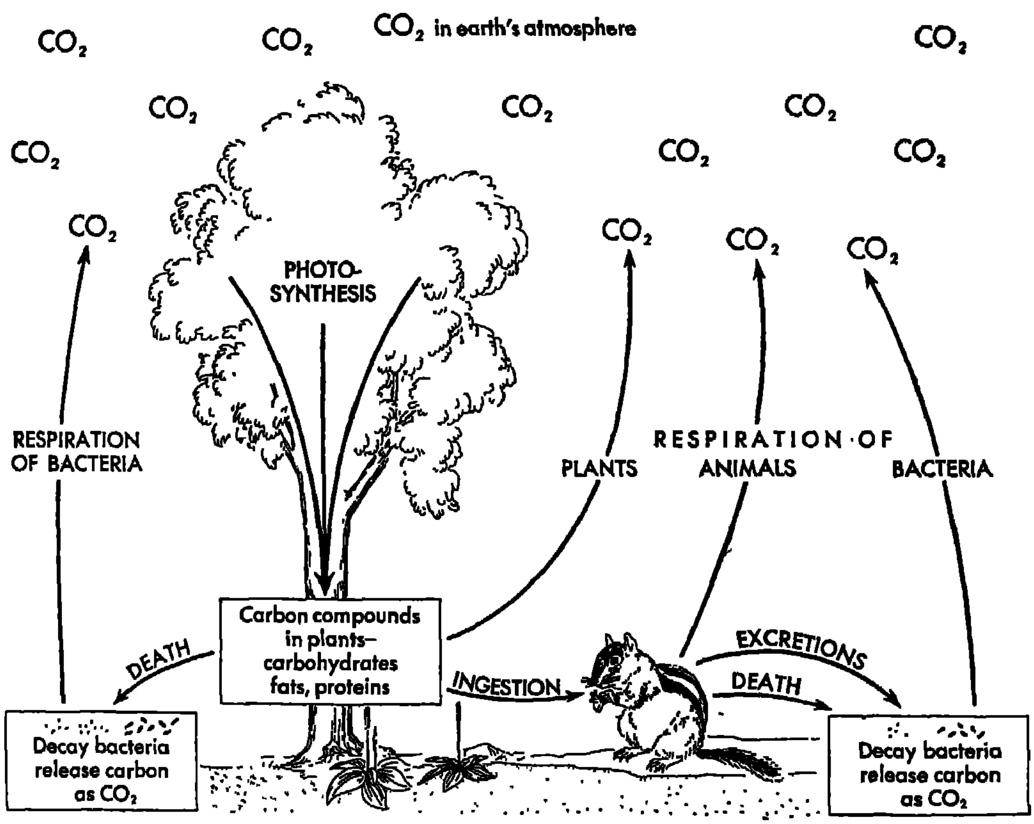


Fig. 39.11. The carbon cycle. The course of carbon atom in its cycle of transformations by plants and animals. From C.W. Young, G.L. Stebbins and F.G. Brooks, *Introduction to Biological Science*, Harper & Brothers, New York, 1956.

Mineral Nutrition of Plants

You have learnt that at one time people believed that plants obtain their nourishment from the soil. Then, when the process of photosynthesis was understood, it became clear that the bulk of the dry matter, consisting of carbon, hydrogen and oxygen, came from air and water. The rest of the dry matter, which may make up 1-15 per cent of the total dry weight, comes from the soil. Recall the classical experiment of van Helmont. He had noted a slight decrease in the weight of the soil. That actually represented the substances taken in by the plant, though van Helmont paid no attention to it. This consisted of a large number of elements which are collectively known as mineral elements. Although minerals form only a small part of the protoplasm, they are nevertheless as important as carbon, hydrogen and oxygen. For example, complete lack of magnesium would not allow the synthesis of chlorophyll, and the plant would collapse.

The earth's crust contains 103 naturally occurring elements. Many of these are present in a dissolved state in the soil, and can be absorbed by the plants. However, not all the elements absorbed by the plant are essential for its growth. Can you think of a method to ascertain which of the elements are essential? This is done by the so-called water culture experiments. Two German botanists, Knop and Sachs, first started such experiments. The method consists of growing plants in glass jars or bottles with the roots immersed in an aqueous solution of inorganic salts (Fig. 39.12). After much trial and error Knop devised a solution consisting of the following salts: calcium nitrate, potassium nitrate, magnesium sulphate and potassium di-hydrogen phosphate. More precise experiments in recent times have shown that there

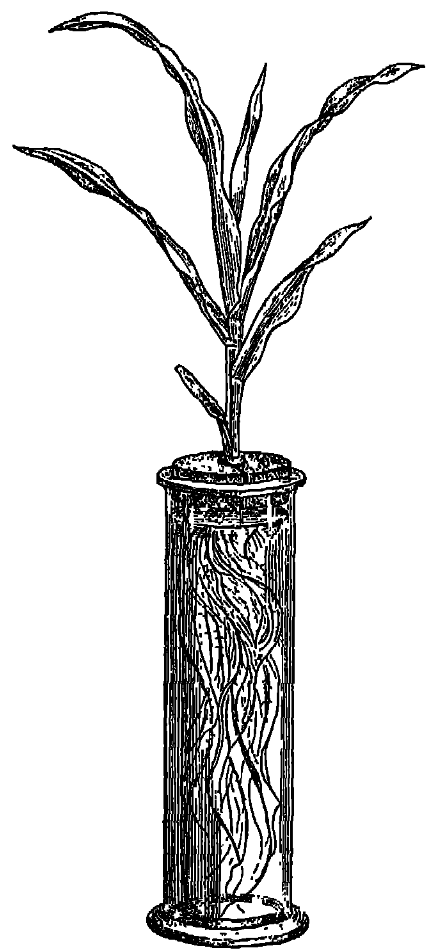


Fig. 39.12. Liquid culture of plants as used by Julius Sachs to investigate the essentiality of mineral elements. Courtesy of the Department of Botany, University of Delhi.

are about 15 elements which are absolutely essential for plant growth, i.e. without these plants would not be able to complete their life cycles. These are carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, iron, molybdenum, boron, copper, manganese and zinc. Of these the first ten are required in fairly large amounts and are, therefore, termed **major elements**. The remaining

five are needed only in slight amounts or traces; these are referred to as **minor** or **trace elements.**

The mineral elements play a very important role in the life of a plant. Magnesium, for instance, is a part of the chlorophyll molecule; calcium is an important constituent of all cell walls; nitrogen, phosphorus and sulphur enter into the making of proteins; iron, zinc, copper and molybdenum are parts of certain enzymes. When plants are unable to obtain any of these elements from the soil they become sick. Quite often the sickness due to the lack of a particular element can be diagnosed from the type of symptoms appearing in different parts of a plant. For example, the deficiency of magnesium results in a yellowish colour of the leaves due to the insufficiency of chlorophyll. Symptoms produced by the deficiency of mineral substances are popularly called **'hunger signs'** of plants (Fig. 39.13).

Absorption of mineral salts. Mineral salts are present in the soil in solution, a thin film of which surrounds each soil particle. The root hairs come in intimate contact with these particles. Various salts pass into the root hairs by the process of diffusion. The salts then diffuse from the root hairs into the cortical cells, and finally enter the xylem elements. Once in the xylem vessels, they are drawn upward along with the stream of water (*see* Fig. 41.1; p. 450).

Three elements—nitrogen, phosphorus and potassium—are used by plants in comparatively larger amounts. Moreover, these elements are readily lost from the upper layers of the soil into the lower ones along with the percolating water. For this reason salts containing these elements have to be frequently added to the fields in the form of mineral fertilizers. Organic fertilizers, made from cowdung and similar materials, contain partially decomposed organic matter in addition to the salts. When these fertilizers are added to the field in addition to the supply of salts, they promote the growth of some micro-organisms in the soil which are beneficial for the growth of plants.

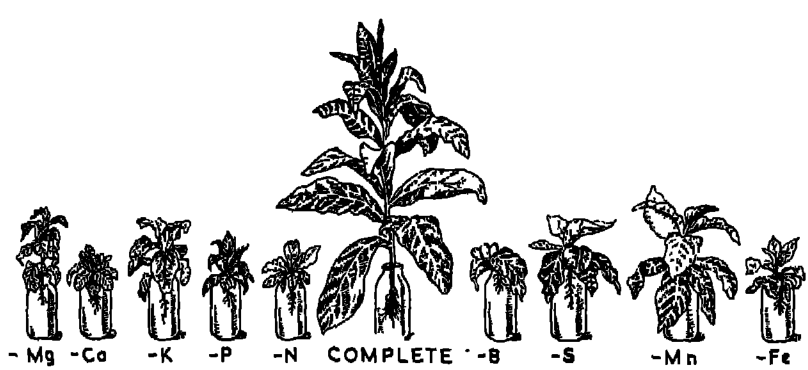


Fig. 39.13. Tobacco plants showing the results of deficiency of one or the other of the essential elements. Courtesy of the Department of Botany, University of Delhi.

Animals require iodine, fluorine, cobalt and sodium in addition to the elements listed for plants. They derive all these from plants directly or indirectly. It happens that plants absorb all the elements present in the soil solution, and make them available to their animal consumers. Some soils are deficient in one or more of the elements required by animals. Under such conditions the plants themselves grow reasonably well but the animal population of such localities may suffer from the deficiency of certain elements.

Sometimes plants absorb certain elements which are not particularly harmful to themselves but may prove highly toxic to animals. A well-established case concerns the element selenium which causes a disease called 'blind staggers' in certain parts of the USA. Radio-active elements, released as waste from atomic energy laboratories and from atomic explosions, are other examples. Animals consuming such plants as are growing on soil containing radio-active elements may accumulate such elements in their bodies and suffer from radiation hazards.

Fixation of Nitrogen

Although we have considered the supply of nitrogen along with mineral elements, the basic source of this element is different from that of the others. All the elements except nitrogen are derived from the disintegration of rocks, but nitrogen is obtained from the atmosphere where it is present to the extent of 78 per cent. However, most plants cannot use this nitrogen directly. They must obtain it from the soil, mostly in the form of nitrates. These are derived from atmospheric nitrogen through several agencies. The most important are certain soil bacteria and blue green algae which have the unique ability to fix atmospheric nitrogen into nitrates. Some of the nitrogenous matter diffuses out of their cells when they are alive, while the rest becomes available in the soil when these organisms die. The mats of blue-green algae found in the rice fields of Bengal enrich the soil which then yields a better crop than if the algae were absent. While many nitrogen fixing bacteria live free in the soil, others inhabit the roots of legumes like peas, beans and groundnuts. The roots of these plants develop abundant swellings (Fig. 19.5; p. 187) which contain masses of rod-shaped bacteria. The latter live symbiotically with the roots. They fix nitrogen, part of which is available to the host plant, and in return obtain carbohydrates from it. When the plant dies, the nitrogen in the roots is added to the soil by the processes of decay and decomposition.

Another source of nitrogen in the soil is the electrical discharges in the atmosphere. The nitric acid formed during this process is washed down with rain water and reacts with a variety of substances to form nitrates in the soil. When the bodies of plants and animals decay, nitrogenous matter is added to the soil. Much of the nitrogen removed from the atmosphere through these agencies is ultimately poured back into it by denitrifying bacteria. These are abundant in soils rich in moisture and organic matter. Thus atmospheric nitrogen enters plants through the soil and from them it goes into the bodies of animals. Death and decay of plants and animals restore the nitrogen to the atmosphere. The main events of the **nitrogen cycle** are shown in Fig. 39.14.

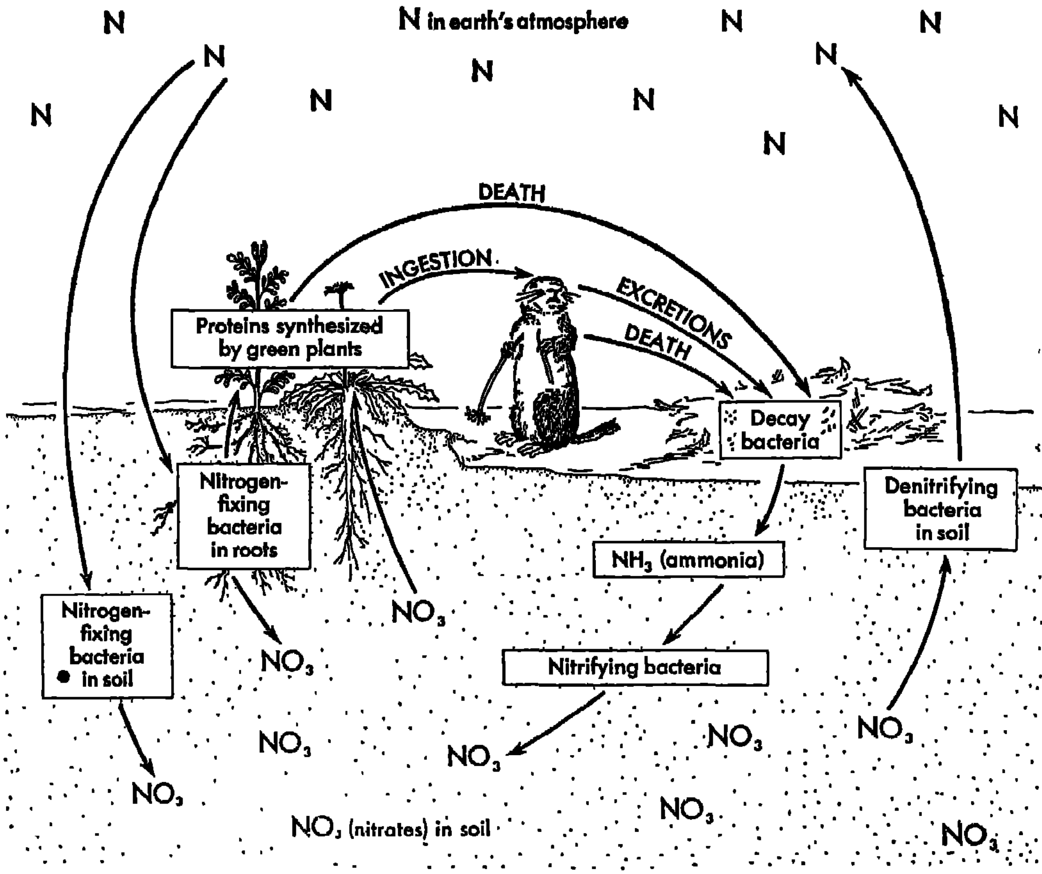


Fig. 39.14. The nitrogen cycle. The relationship between living things and the nitrogen atom. From C.W. Young, G.L. Stebbins and F.G. Brooks, *Introduction to Biological Science*, Harper & Brothers, New York, 1956.

SUMMARY

Living organisms are either autotrophic or heterotrophic. The autotrophs can manufacture their own food from simple substances such as water, carbon dioxide and minerals. The energy required to bring about these syntheses may be derived from sunlight as in the photosynthetic autotrophs, or from chemical reactions as in the chemosynthetic autotrophs. The non-green plants and all animals, including man, depend directly or indirectly on the green plants for the supply of food and oxygen.

Photosynthesis is the process of manufacture of carbohydrate from carbon dioxide and water by the green tissues, using energy of sunlight. Oxygen is given out as a by-product. Glucose, the first product of photosynthesis, is translocated from leaves to the other parts, and is used to produce all the other materials of which the plant body is made. Two sets of reactions take place in the manufacture of sugar. Light is essential only in the first phase in which water molecules are split in the chloroplasts, and oxygen is set free. In the second set of reactions which can occur in light as well as in dark, carbon dioxide is reduced to form carbohydrates. The carbon dioxide stored in the bodies of plants and animals is returned to the atmosphere by respiraton and by the decay of animal excreta and dead bodies by bacteria and fungi.

There are certain elements which are absolutely essential for the growth of the plant. These are carbon, oxygen, hydrogen, phosphorus, potassium, nitrogen, sulphur, calcium, magnesium, iron, boron, copper, manganese and zinc. Except for nitrogen, all the other major and minor mineral elements are derived from the soil. Nitrogen comes from the atmosphere by nitrogen fixation and electrical discharges. Like carbon, there is also a cyclical flow of nitrogen in Nature.

QUESTIONS

1. Ordinarily, photosynthesis proceeds much faster than respiration. Under what conditions would the two processes be equal? Does this happen in Nature?
2. What are the essential elements for plant growth? Name the source from which each element is derived.
3. Trace the path of a carbon atom from the atmospheric carbon dioxide to the glycogen molecule in the cells of the liver.
4. What is wrong with following statements?
   (a) The food of plants consists of water and mineral elements obtained from the soil, whereas animals require organic foods like proteins and fats.
   (b) All plants give out oxygen during the day and carbon dioxide during night.
5. State whether the following statements are true:
   (a) All animals depend upon plants for food.
   (b) Only chlorophyllous cells can carry out photosynthesis.
6. When green plants are included in an aquarium, the fish can live happily even if the water is not changed frequently. Explain.
7. In the experiment on a variegated leaf of *Manihot* you learnt that the non-green parts do not form starch. The potato tuber is also devoid of chlorophyll, yet it contains starch. Explain.

8. What was wrong with van Helmont's inference?

9. Will a plant be able to carry on photosynthesis if the lower surface of its leaves is coated with vaseline?

10. How is it possible for carbon dioxide to enter and for oxygen to escape from the stomata at the same time?

11. A green potted plant is kept in a sealed glass bell jar from which the oxygen has been removed. Will the plant live longer in light or in dark? What will be your answer if the plant were a mushroom?

12. Animals require certain elements like iodine, fluorine and sodium which plants do not require. From where do the animals then get these elements?

FURTHER READING

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CHAPTER 40

Heterotrophic Nutrition

IN the preceding chapter we learnt that all animals, including man, are heterotrophs. Directly or indirectly we depend upon plants for all our food supply. You may argue that your dog can live on meat and milk alone and hence it is not dependent upon plants. But think of the source of the meat and milk which your dog takes. The meat may be derived from a goat which eats the leaves of plants. The cow which supplies milk also lives on herbs. Hence ultimately your dog is dependent upon plants for the supply of its food. In figure 40.1 you see a **food chain** and you can think of still others yourself. You will now understand that the saying 'all flesh is grass' is absolutely correct. Whether we are vegetarians or non-vegetarians we must ultimately depend upon the food made by green plants. Having known this, let us now proceed to learn more about foods and the various modes of heterotrophic nutrition. Although we shall concern ourselves mainly with human nutrition, let it be said at the outset that from a chemist's point of view, the food of every organism—whether it is a mosquito, mouse, lion, mould or rice plant—is the same.

Chemically speaking, the various kinds of foods like bread, butter, cheese, rice, sweets, vegetables, meat, milk, fruits, etc. can be sorted into six categories, namely, (1) carbohydrates, (2) proteins, (3) fats, (4) vitamins, (5) minerals and (6) water. Figure 40.2 shows the common foodstuffs

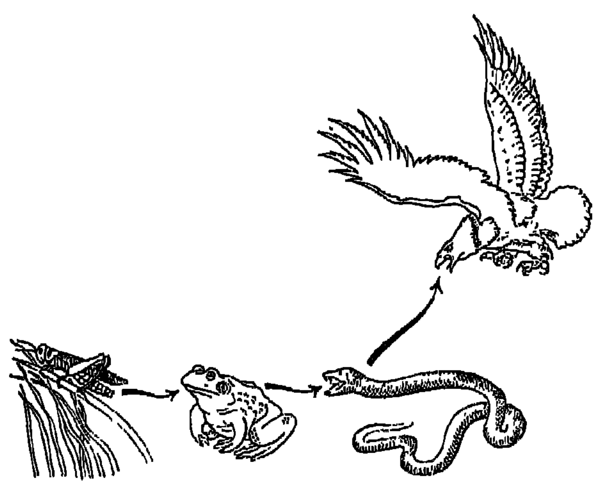


Fig. 40.1. Directly or indirectly every organism must ultimately depend upon green plants for its food. In the food chain shown here, the snake, frog and grasshopper link the starting point of the chain (green plant) with the last point (eagle, a carnivorous animal). Courtesy of the Department of Botany, University of Delhi.

which can adequately supply the necessary constituents of food. The omission of any one of these would retard our growth and make us sick. Let us see why.

Importance of Carbohydrates, Fats and Proteins

Every type of activity, like running, swimming, breathing and talking, requires expenditure of energy. Inside our bodies such activities as the beating of the heart, the contraction and expansion of the lungs, and several metabolic processes go on continuously whether we are awake or asleep. For all these also we need energy which we obtain by the burning, or more properly, by the oxidation of carbohydrates, fats, and sometimes proteins which we procure through our food. Table 1 shows the average daily requirement of energy at different ages.

TABLE 1—DAILY REQUIREMENTS OF ENERGY

1. Child under 2 years	1,000	Cal
2. Child from 2 to 5 years	1,300	,,
3. Child from 6 to 9 years	1,700	,,
4. Girl from 10 to 12 years	2,000	,,
5. Girl from 12 to 14 years (light work)	2,200	,,
6. Active boy (12-14 years) and girl (15-16 years)	2,600	,,
7. Boy (15-20 years), light work	3,000	,,
8. Man, moderately active	3,200	,,
9. Man, doing hard labou	3,500-5,000	,,

The unit of measurement of energy is a **calorie** (cal) which is the amount of heat required to raise the temperature of one gram of water by one degree centigrade. One **kilocalorie** (Kcal or Cal) is equal to 1,000 calories. The amount of heat energy given out by a substance on oxidation

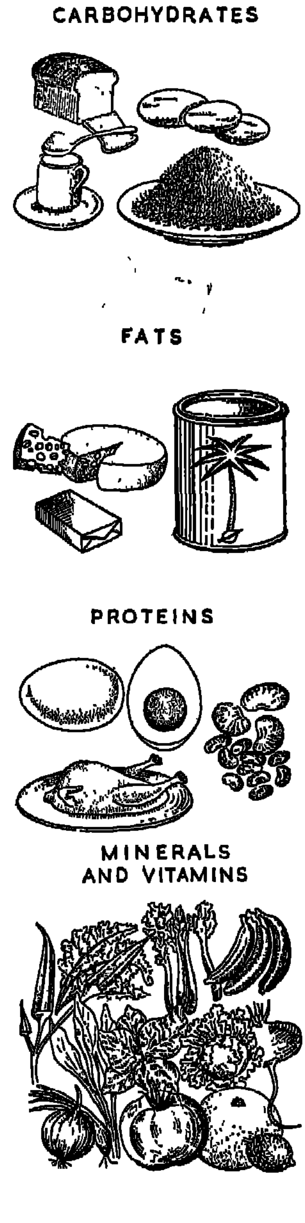


Fig. 40.2. Some common foodstuffs which form good sources of carbohydrates, fats, proteins, minerals and vitamins. You should select the main part of your everyday diet from these four food groups. Courtesy of the Department of Botany, University of Delhi.

can be determined by means of a calorimeter (Fig. 40.3). The Calorie requirement of an individual depends not only on age but also on the nature of the work done. Thus, a typist or a maid needs much more energy than a person in sleep (Fig. 40.4).

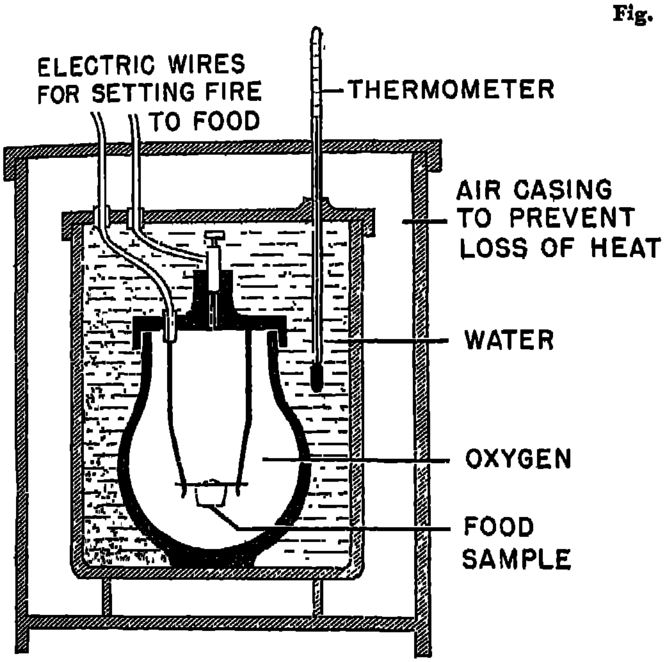


Fig. 40.3. The calorimeter consists of a steel bomb surrounded by water in a watertight jacket. This in turn is contained in an air casing through which no heat can escape. The food whose energy value has to be determined is weighed and placed inside the bomb which is filled with oxygen. A measured quantity of water is poured into the jacket. Through the two wires connected to the food, electric current is passed to produce a spark. The food burns instantly in pure oxygen. The heat produced from the burning of the food raises the temperature of the surrounding water. A thermometer dipped in this water registers the rise in temperature. From C. Gramet and J. Mandel, *Biology Serving You*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1958.

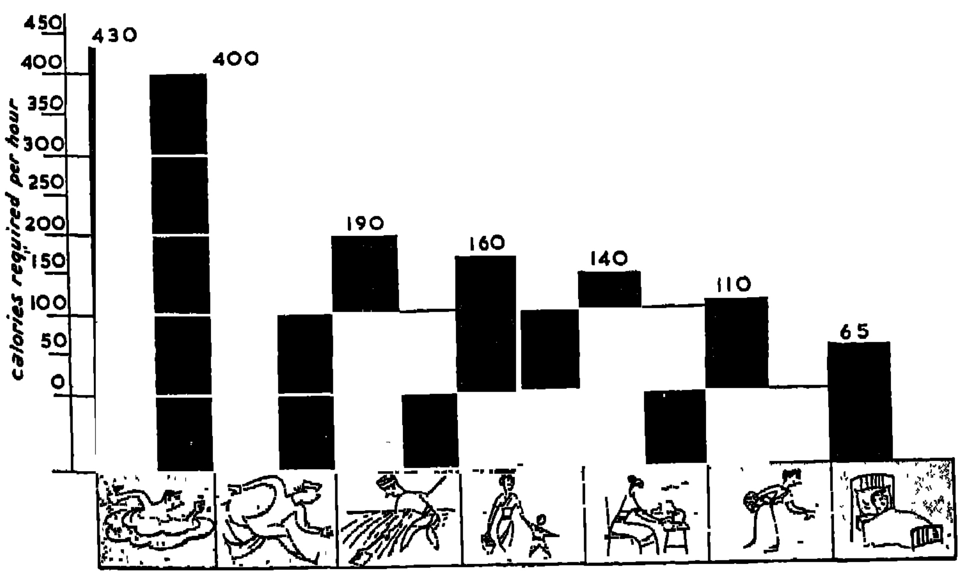


Fig. 40.4. The number of Calories one needs every hour depends on the type of work one does. Courtesy of the Department of Botany, University of Delhi.

Even when an organism is completely at rest, that is, when activities like locomotion, reproduction and feeding are completely suspended, some energy is expended just to keep it alive. The metabolic activity in this condition is kept at its lowest—there is a minimum of respiration, minimum of heart beat and so on. The energy expended by an organism in this state indicates the so-called **basal metabolism.** It is measured indirectly by determining the volume of oxygen used in a given time. By knowing the amount of oxygen needed to oxidize a particular amount of glucose, and the calories obtained thereby, it is possible to work out the caloric expenditure in the basal metabolism of an organism. This naturally varies with the age and sex of the individual.

All of the major classes of food materials can provide us energy. Weight for weight, fats are the most important because a gram of fat, upon oxidation, gives nearly twice as much energy as that obtained from carbohydrates and proteins (*see* Table 2). However, the oxidation of fats requires a lot more oxygen. Furthermore, fats are immiscible with water. Hence, they serve mainly as storage foods in the body, to be drawn upon only when the more easily oxidizable carbohydrates are exhausted. Besides providing energy, fats and carbohydrates also have other roles to play in the cellular factory. The cytoplasmic membranes are partly built from fat molecules which are responsible to a large extent for their semipermeability. Carbohydrates, on the other hand, are extremely valuable as constituents of various cell wall materials like cellulose and pectin.

TABLE 2—ENERGY VALUES OF DIFFERENT FOODS

Food	Approximate amount of oxygen required (litres)	Approximate amount of energy liberated (Cals)
1 gram of Carbohydrate	0.83	4.2
1 gram of Fat	2.00	9.5
1 gram of Protein	0.93	4.2

Although proteins too can be oxidized to provide energy, they are generally utilized for building enzymes and for the renewal of protoplasm whose wear and tear constantly requires a new synthesis of proteins. An average person needs about 70 to 100 grams of proteins everyday. They are broken down in the body into smaller fragments or amino acids. The amino acids are then reassembled to form new protein molecules.

Water, Minerals and Vitamins

You might be wondering why we put water as one of the essential items of food. Water not only makes up nearly one-third of our body weight but also serves as a medium of transport of food materials and waste products from every part of the body.

Besides the three major groups of food—proteins, fats and carbohydrates—we also need vitamins, and minerals like potassium, calcium, magnesium, phosphorus, iron and iodine for the various functions of the body. Our requirement of minerals and their sources are given in Table 3.

Vitamins are organic substances which are required in extremely small quantities and yet have profound effects in the body. They are thus a class quite apart from the major classes of foods. We depend upon plants for the supply of all the vitamins excepting vitamin D which is synthesized in the skin in the presence of sunlight. Table 4 shows from where we can get our vitamins, why they are required and what will happen if we do not have them.

TABLE 3—THE ROLE AND SOURCES OF MINERALS

Minerals	Essential for	Sources
Sodium	Blood and other body tissues	Table salt, vegetables
Calcium	Bones and teeth, heart and nerve action, clotting of blood	Milk, whole-grain cereals, vegetables, meat
Phosphorus	Bones and teeth, formation of protoplasm	Milk, whole-grain cereals, vegetables, meat
Magnesium	Muscle and nerve action	Vegetables
Potassium	Blood and cell activities, growth	Vegetables
Iron	Formation of red blood corpuscles	Lettuce, leafy vegetables, liver, meat, raisins, prunes
Iodine	Synthesis of thyroid hormones	Sea foods, water, iodized salt

The complete list of vitamins known to science is much larger, and only the more important ones have been listed below.

TABLE 4—FUNCTIONS AND IMPORTANT SOURCES OF VITAMINS

Vitamins	Essential for	Deficiency symptoms	Best sources
Axerophthol (Vitamin A)	Growth Health of the eyes Functions of the cells of the skin and mucous membranes	Retarded growth Night blindness Susceptibility to infections Changes in skin and membranes Defective teeth	Fish liver oils, liver and kidney, yellow vegetables, fruits, tomatoes, butter, egg yolk
Thiamine (Vitamin B_1 or F)	Growth Carbohydrate metabolism Functioning of the heart, nerves, and muscles	Retarded growth Loss of appetite and weight Nerve disorders Fatigue Faulty digestion	Seed food, meat, soybeans, milk, chicken
Riboflavin (Vitamin B_2 or G)	Growth Health of the skin and mouth Functioning of the eyes	Retarded growth Dimness of vision Inflammation of the tongue Premature ageing Intolerance of light	Meat, soybeans, milk, green vegetables, eggs, chicken
Pantothenic acid (Vitamin B_3)	Carbohydrate metabolism Formation of fur in mammals	Inflammation of skin	Cane molasses, yeast, meat, liver, kidney, milk, eggs
Nicotinamide (Vitamin B_5)	Growth Carbohydrate metabolism Functioning of the stomach and intestines Functioning of the nervous system	Smoothness of the tongue Skin eruptions Digestive disturbances Mental disorders (pellagra)	Meat, peanut butter, potatoes, whole-grain cereals, tomatoes, leafy vegetables

TABLE 4—Contd.

Cyanocobalamin (Vitamin B_{12})	Formation of red blood corpuscles Synthesis of nucleic acids Nitrogen metabolism	Anaemia	Liver
Ascorbic acid (Vitamin C)	Growth Maintaining strength of the blood vessels Teeth development Health of gums Wound healing	Sore gums Haemorrhages around the bones Tendency to bruise easily (scurvy)	Citrus fruit, tomatoes, leafy vegetables
Calciferol (Vitamin D)	Growth Building and maintaining bones, and teeth	Soft bones (rickets) Poor teeth development Dental decay	Fish liver oil, liver, fortified milk, eggs
Tocopherol (Vitamin E)	Normal reproduction	Loss of fertility	Leafy vegetables, milk, butter
Phylloquinone (Vitamin K)	Normal clotting of the blood Normal liver functions	Haemorrhages	Green vegetables, soybean oil, tomatoes, also synthesized by bacteria in the gut

Importance of vitamins. The total or combined vitamin requirement of a person is very small, indeed not more than a few milligrams per day. However, as shown in Table 4, their absence or insufficiency in the diet results in many troublesome ailments. "What do vitamins do in the body?" might be your next question. Well, several vitamins have been found to form an important part of the enzyme molecules in cells. Since all living activity stems from chemical reactions mediated by enzymes, the absence of vitamins results in disruption of the functions of the body.

The existence and importance of vitamins was recognized much before their chemical nature was worked out. Therefore in earlier days they were simply called A, B, C, D, and so on. The chemical structure of most of the vitamins has been worked out and they are now usually referred to by their actual chemical names.

Have you known some apparently well-fed people who always complain of one or the other ailment? It is quite likely that they do not have any organic disease, but their apparently 'rich diet' may be deficient in vitamins. This can happen very easily because most vitamins are unstable compounds. They are easily destroyed by heat and by exposure to the oxygen of the air. Some, like the water soluble B vitamins, are heat stable, but if the water in which the food was cooked is rejected, the body gets almost none of these vitamins. Fortunately it is now possible to supplement one's diet with synthetic vitamins available in the form of pills.

Discovery of vitamins. There was a time in the history of biology when most biologists believed that disease could result only from invasion of the body by external agents such as microbes, viruses and poisons. In other words, people thought of disease in terms of the presence rather than the absence of something in the body. It became known, by trial and error, that certain diseases could be cured only by a

change in the diet, especially by consuming plenty of vegetables and fruit juices. The captains of ships had discovered that diseases like scurvy and rickets, which often afflicted sailors during long sea journeys, could be got over by including fresh lemons in the ration of the sailors.

However, the event that led to a long chain of experiments finally culminating in the discovery of vitamins was a chance happening. We relate that incident here to demonstrate to you how an alert and prepared mind can catch the significance of a seemingly insignificant happening, and, work it up to unravel the mysteries of Nature.

In 1896 a Dutch physician named Christian Eijkman was sent to Java to investigate into the causes of a paralytic disease called **beri-beri.** This word literally means 'I cannot, I cannot', and expresses the symptoms of the disease. The muscles of sufferers from beri-beri become stiff and painful due to degeneration of nerves, and the victims feel extremely weak.

One day Eijkman noted that some of the experimental fowls in his hospital yard developed symptoms of beri-beri and started dying in dozens. A few days later Eijkman was looking through his diary and noted that the birds had started suffering 2-3 days after a certain date when they were put on a diet of polished rice (that is, rice with bran or hull removed). The cheaper, unpolished rice, which was usually fed to the fowls, had gone out of stock on that date and was substituted by polished rice from the soldiers' mess. Could polished and unpolished rice make any difference? Eijkman decided to test it. The next day he procured some unpolished rice and divided his fowls into two batches. One batch received the polished rice; the other, the unpolished rice. The fowls that went back on unpolished rice recovered from the ailment and were dancing about and feeding as before. The condition of the fowls that continued to receive the polished rice became still worse. Further work by Eijkman and by a Polish biochemist, Casimir Funk, showed that the rice bran contains a substance which can cure not only beri-beri, but also some other nervous disorders. The substance was named simply vitamin, and is now called vitamin B_1 or thiamine.

Ingestion of Food

In the simplest organisms like *Amoeba*, the food is taken in at any place on the cell surface and it moves directly into the cytoplasm. Other unicellular protozoa, like *Paramecium* and *Vorticella*, produce a current in the water with the help of cilia, and the food particles are carried with the current to a depression in the cell wall through which they pass into the cytoplasm. In *Hydra* the food is ingested with the help of tentacles. The earthworm has a muscular pharynx which is pushed out to swallow large amounts of wet earth containing food in the form of decomposed leaves and other organic substances. Arthropods, like cockroaches and beetles, have peculiar mouth parts adapted for catching and cutting, comparable to our knives and forks. The vertebrates—fishes, frogs, reptiles, birds and mammals—have well-developed jaws and can take in large pieces of food. Thus, as the animals have become larger and more evolved, the structures for taking in food have become better developed.

In some heterotrophs, such as the insectivorous plants, there is a process similar to ingestion. In the Venus fly-trap, for example, small insects which happen to alight on the leaf surface are ingested as the two halves of the leaf snap together. The animal is then digested with the help

of enzymes released from the surface of the leaf. In other members the insects get enmeshed in the tentacles found on the surface of the leaf. The insects are then acted upon by the enzymes and digested. This process is similar to that found in *Hydra*. You will learn more about the insectivorous plants later in this chapter.

Intra- and Extracellular Digestion

It is clear that all living organisms must digest their food to survive. The only forms that do not have to digest their food are parasites, like the tapeworm which lives in the intestine of vertebrates and gets predigested food from the hosts.

In the protozoans, sponges and molluscs, which feed on very small organisms or their juices, the food directly enters the cells where it is digested by enzymes. This is called **intracellular digestion.** However, in the majority of multicellular animals, particularly those which ingest larger food masses, the food passes through the alimentary canal into which several digestive enzymes are secreted to break it down to simpler molecules. This process, in which the food is digested outside the cells, is called **extracellular digestion.** In general, extracellular digestion is found in all advanced groups of animals.

The Various Steps of Digestion

In man the food is mixed with saliva and is ground to a fine paste by the teeth. Even the sight of tasty food may promote the secretion of saliva. This has two functions. First, it makes the food easier to swallow; secondly, it secretes the enzyme amylase which sets into motion the process of digestion by converting starch into sugar.

From the mouth the food passes into the stomach and presses against its wall. The pressure stimulates the gastric glands to secrete pepsin, a proteolytic (protein digesting) enzyme, which works in an acidic medium. The presence of food also causes the liberation of a hormone from the lining of the stomach which stimulates the secretion of hydrochloric acid. This mixes with the food mass and makes it highly acidic. In the acidified medium pepsin breaks down proteins into peptides (smaller chains of amino acids).

After it has become a soupy mass, the food enters the upper part of the intestine, the duodenum. The pancreatic duct from the pancreas and the bile duct from the liver open into the duodenum. The pancreas secretes a fluid which not only neutralizes the free acid in the food mass coming from the stomach, but also makes it alkaline. The pancreatic fluid also contains the enzymes trypsin, amylase and lipase all of which act only in an alkaline medium. Trypsin and amylase continue respectively the digestion of protein and starch which was begun in the stomach and mouth. Lipase breaks down fats to fatty acids. This is facilitated by the bile salts which break up fats into small droplets that can be easily acted upon by lipase.

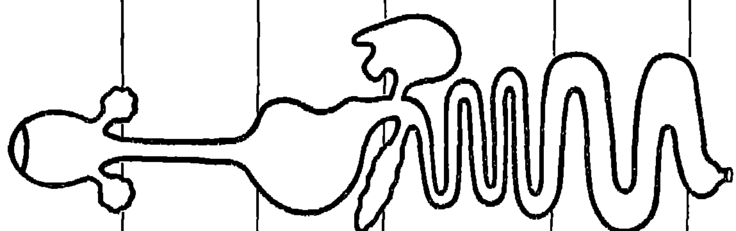
Absorption of Food

The digestion of carbohydrates, fats and proteins is completed in the small intestine. The products are absorbed through the intestinal wall and picked up by the blood. The intestinal wall has numerous, inwardly directed prolongations or villi (Fig. 28.28, p. 308) which increase the surface area for the absorption of food. They are richly supplied with blood capillaries and lymph vessels. The sugars and amino acids are absorbed into the blood while

fatty acids and small fat globules are picked up mostly by lymph vessels.

The food that remains undigested in the small intestine is pushed into the large intestine. Much of the water is absorbed by the wall of the large intestine, and the undigested matter gets concentrated and excreted at intervals through the anus. The elimination of faeces is under the control of nerves. The anal opening has two circular muscles which can be opened and closed at will. Figure 40.5 presents a summary of the various steps of digestion enumerated above.

The process of digestion in the invertebrates as well as in the vertebrates is similar because, as said before, the food of all kinds of organisms is chemically the same. All organisms have enzymes for digesting proteins, fats and carbohydrates. Thus glucose, fatty acids and amino acids are the end products of digestion in an amoeba, a cockroach, a cat, a lion, a mango tree



PARTS OF THE DIGESTIVE SYSTEM	mouth salivary glands	oesophagus	stomach	small intestine	large intestine	anus
MAJOR FUNCTION	food entrance some digestion of starch	carries food to stomach	protein digestion	digestion and obsorption	salts and much water reabsorbed undigested wastes collect	waste exit
MAJOR TYPE OF ENZYME ACTING	amylase		pepsin	trypsin, lipase, for breakdown of protein fragments		
SOURCE OF ENZYME	salivary glands		gastric glands	pancreas small intestine		
SUBSTANCE ACTED UPON	cooked starch		proteins	protein fragments fats complex sugars		
PRODUCT	complex sugar		large fragments of proteins and some amino acids	fatty acids glycerol simple sugars amino acids protein fragments		

Fig. 40.5. Summary of the digestive process. Note the regions where digestion and absorption of food takes place. From *BSCS, Biological Science: Molecules to Man*, Houghton Mifflin Company, Boston, 1963.

as well as in man. Some, however, show great specialization as they can digest only a particular type of food. For example, a mollusc called *Teredo* which lives inside the wooden hulls of ships, can digest cellulose (a complex carbohydrate). Its digestive gland produces an enzyme, cellulase. Besides *Teredo* some protozoans also possess cellulase. The digestion of cellulose by termites, cows and other herbivorous animals is a different story. In these animals the digestion of cellulose is actually done by bacteria and protozoans living in their digestive tracts. In the cow these micro-organisms are present in the rumen or the first chamber of the stomach. The micro-organisms are so essential for termites that if they are artificially removed from their alimentary tract, the termites die of starvation.

The Story of the Digestive Process—A Discovery by Chance

From this simple account of the mechanism of digestion you might think that this knowledge was acquired very easily. It may perhaps surprise you to learn that even up to the year 1815 people had only the vaguest ideas about the process of digestion. Although it was understood that food passes through the alimentary canal, the changes it undergoes were largely a matter of speculation. The famous Greek biologists, Aristotle and Hippocrates, thought that the food was somehow 'cooked' in the stomach. This was evidently an unsatisfactory explanation, because cooked food and digested food are so markedly different from each other. Some other biologists thought that the food undergoes decay or fermentation in the stomach. This idea probably arose from the observation that both decayed matter and faeces give out a foul smell. The lack of correct understanding may perhaps be ascribed to the fact that it was considered sinful to cut open a live or even a dead human body for any kind of study.

The first scientific experiments on the process of digestion in man were performed as late as 1822. Like so many other scientific discoveries, this too was favoured by a fortunate accident. The site of this chance happening was a small village near Lake Michigan, USA. It so happened that on a Sunday morning in 1822, a factory worker named Alexis St. Martin was accidentally shot by a bullet in the stomach. His clothing was driven into the wound, and the stomach and lungs were protruding from it. The food was pumping out of the victim's stomach. A military doctor named William Beaumont was called to attend on the patient. Dr Beaumont nursed him back to health, but during the process of wound healing it so happened that the margins of the wounds on the body wall and the stomach got fused with each other. A permanent window was, therefore, left in the stomach of St. Martin. He could eat and drink normally, but he had to put a bandage on the wound in order to prevent the food from escaping through the window. The factory in which this man was employed refused to take him back in the job. However, Beaumont took pity on him and kept him as a domestic servant.

One day the servant was lying sideways in his bed. The doctor happened to pass by him and noticed the softened bits of meat in his stomach. Beaumont realized that he had an excellent opportunity to study the process of digestion in his servant's alimentary canal. St. Martin thus became his experimental object. He conducted many experiments concerning the digestive

process and made detailed notes. Beaumont observed that when the food enters the stomach, a juice oozes out of the stomach wall. By feeding different types of food to his 'experimental animal' he came to know which of the foods were digested in the stomach. He invented many remarkable techniques for his study. He used to lower pieces of food into St. Martin's stomach by means of a silken thread and noted the time taken for its digestion. He also demonstrated that the juice collected from the stomach can bring about the digestion of food in a test tube just as it does in the human body. Thus it came to be known that digestion was brought about neither by any 'vital touch of the human body' nor by putrefaction. Beaumont conducted as many as 238 experiments on his servant, and in 1833 he brought out a book on 'Experiments and Observations on the Gastric Juice and the Physiology of Digestion'—a standard work even today. This caused a sensation in the medical world and marked the beginning of experimental physiology. Subsequently, many more people conducted experiments on human beings as well as on other animals, and gradually the process of digestion and the functions of various intestinal juices came to be clearly understood.

Beaumont's Guide to Good Eating Habits

Beaumont used his 'human test tube' to carry out an amazing variety of experiments. We relate here some of his observations together with those of others to help you develop good eating habits.

Beaumont found that the state of mind, that is, the emotional condition of man has a surprising effect on the digestive process. Whenever St. Martin lost his temper, had some fear, or was otherwise off his mood at mealtime, the digestion was slower. This resulted from a poor secretion of the gastric juice. On the other hand, the digestive system worked very smoothly when St. Martin was cheerful. Thus the oft-repeated axiom, 'don't take your troubles to the dining room,' has a scientific basis. Similarly, a nicely laid dinner table in a calm, well-kept room, a bunch of flowers on the table and pleasing music at mealtime are not mere luxuries but a positive help in promoting good appetite and proper digestion.

Another interesting finding of Beaumont was that the secretion of gastric juice is markedly decreased during hot and humid weather. This finding warrants the use of light and easily digestible food in summer, as is commonly advised by physicians. The limited amount of gastric juice secreted by the stomach wall can digest only a certain quantity of food. If more food is taken than can be digested by the limited quantity of gastric juice, indigestion results. The extra food may lie undigested in the stomach for as long as 48 hours. Yet another finding was that fatty foods take much longer to get digested than non-fatty foods. This is because fats require extra digestive steps.

Diet and body weight. Have you ever considered why some people become unusually fat? While the tendency to become fat or remain slim is partly determined by heredity, one can exercise some control over one's body weight by regulating one's food habits. If the body gets food in excess of its requirements, the extra food is converted partly into glycogen (a kind of starch) and partly into fats. Glycogen is stored in the liver cells and can be

mobilized easily when the amount of sugar in the blood falls below a certain minimum level. However, the storing capacity of the liver cells being limited, most of the excess food is converted into fats which may collect in the form of a thick layer below the skin. This fat tissue is an almost useless weight that has to be carried by the body all the time. Not only that, for every kilogram of weight added to the body, the heart must pump the blood along an additional distance of 1.5 kilometres of blood capillaries. This means extra work for the heart, and the possibility of its early breakdown. Moreover, excessive fat in the body also results in a condition called atherosclerosis. In this the finer arteries are almost blocked by the deposition of tiny fat globules. Although many methods are recommended for reducing weight, by far the best is to cut down the calorific intake in terms of reduction in carbohydrates and fats.

Balanced diet. The Table on page 434 of the calorific requirements of a human being should not make you think that you can meet it from just any class of foods. While all the three major types of food can yield energy, they also have certain specific roles to play in the body. In other words, for normal growth and development one must take a balanced diet, that is, a diet consisting of all classes of foods in the right proportion. Most healthy people can carry on well with a diet that contains 60 per cent carbohydrates, 25 per cent fats and 15 per cent proteins, plus of course, minerals and vitamins. The substitution of one type of food for another results in defective growth. The diet of the inhabitants of a given area is often well reflected in the general health of the people. Thus a study made by some military doctors in 1937 showed that men from the northern states of India who took a regular protein-rich diet—comprising wheat, beans, milk and meat—were heavier and sturdier, and made very good soldiers. In contrast, men from the southern states whose staple food was polished rice, beans and vegetables, but no meat or milk, made less efficient soldiers.

Special Modes of Heterotrophy

Insectivorous plants. There are some green plants which obtain their nourishment partly from the soil and atmosphere and partly by catching and digesting small insects (Fig. 13.4, p. 132). They are, therefore, partially heterotrophic. They generally possess specialized leaves to trap insects. When an insect alights on such a modified leaf, it either gets stuck in the glandular secretion of the leaf, or it is entangled in the hairy outgrowths of the leaf. The trapped insect struggles to death, and its proteins are digested by proteolytic enzymes secreted by the epidermis of the leaf. The amino acids are then absorbed by the plant, thus supplementing its nitrogen supply. A few examples of insectivorous plants are given below.

Drosera (sundew) is a small herb common in wet meadows. The upper surface of each leaf blade is covered with hairs which have glands at their tips. The hairs bend and close up on the visiting insect to trap it. The tips of the hairs secrete proteolytic enzymes.

Aldrovanda, found in the salt marshes, south of Calcutta, is a rootless aquatic herb. The wiry stems bear whorls of leaves each of which has a quadrangular blade whose margins bear long teeth. The two halves of the blade are bent upwards somewhat resembling the wings of a butterfly at rest. Along the midrib of the leaf there are

sensitive trigger hairs. The slightest touch to them causes the leaf to close up. The long teeth on the curved margin of the leaf become interlocked so that the insect has no chance to escape. The two halves of the closed leaf are tightly pressed against each other. The closed leaf acts like a temporary stomach in which the digestive fluid is released from the glands.

Utricularia (bladderwort) is a common weed in stagnant pools and ponds throughout the country. The plant bears finely dissected submerged leaves some of which are modified into bladders or utricles. The latter may be up to 0.3 cm in diameter. The inner wall of the bladder has 3- or 4-pronged digestive glands. The bladder is provided with a valve door which opens only towards the inside. When a small insect or some other animal touches the hairs present on the valve door, it opens and lets in the prey along with some water. The door does not open again as long as the bladder is full of water. Death, decay and digestion of the insect follow.

Nepenthes (pitcher plant) is found in Assam and Ceylon. The lower part of the petiole is flattened and the upper part forms a coiled tendril which may twine around a support. The lamina of the leaf is modified into a pitcher-like structure and its tip forms an immovable lid. The lid is coloured and attractive to insects. The pitcher may be as much as 15-30 cm long. The edge of the pitcher is slippery and curved in such a manner that insects which have slid down cannot climb up the steep wall. Moreover, small insects get drowned in the digestive fluid secreted by glands lining the pitcher.

Parasites. While walking through a mango orchard you might have noticed woody branches of mango trees infested with a broad-leaved plant called *Dendrophthoe.* It bears green leaves so that it can produce its own carbohydrates, proteins and fats, but it obtains minerals and water from the mango plants through haustoria. *Dendrophthoe* is, therefore, called a **partial parasite.** If you examine the junction of the two plant tissues you will notice that the vascular supplies of the two are inter-connected. The parasite deprives the host of only a part of its food, and the host does not suffer much. However, if a large number of parasites grow on the same host tree, as sometimes happens, the host becomes weaker and eventually dies.

Cuscuta (dodder) is another parasite whose yellowish thread-like stems twine around the branches of other plants (Figs. 10.7 and 10.8, p. 104). It is a **total parasite.**

A large number of bacteria, fungi and protozoa live inside the bodies of animal and plants. In addition to consuming food these endoparasites often release poisonous substances which cause disease or sickness in the host. The malarial parasite is one such example. Tapeworms and roundworms are also parasites which live in the intestine of man and other vertebrates.

Saprophytes. You must have noticed that the dead bodies of plants and animals decay and disorganize, and in due course of time practically nothing is left of them. During this process of disorganization, some of their constituents escape into the atmosphere in the form of carbon dioxide and other foul-smelling gases. However, minerals and some partly decayed organic matter (called humus) may get mixed with the soil. The breaking up and decomposition of the dead bodies are brought about by a number of fungi, bacteria, protozoa, termites, etc., which are examples of saprophytes. They

break down the dead organic matter into simpler compounds by secreting extracellular enzymes, and absorb the soluble materials for their nutrition.

Symbiosis. There is yet another mode of nutrition in which two different kinds of organisms pool together their nutritional resources. One good example is lichen—a composite organism consisting of an alga and a fungus living together. The fungus holds the algal cells in its mat of web-like hyphae and supplies them with water and minerals. The alga, on the other hand, carries on photosynthesis and supplies most of the organic food to the fungus. The two thus gain mutually from one another. Such a living together of organisms with mutual help is called symbiosis. There are also examples in the animal kingdom in which algal cells live symbiotically in the bodies of the animals. Well-known instances are some hydras, jellyfishes, corals and a sponge (*Spongilla*).

However, a symbiotic relationship does not necessarily involve the participation of a photosynthesizing organism. It may also exist where both the partners are non-photosynthesizing. In this category come those organisms which help in the process of digestion of food by producing certain enzymes which the other organism is incapable of producing. Common examples are the protozoans living in the gut of termites, and the bacteria living in the rumen of ruminants. The nodules on the roots of the pea and related plants are yet another example of a symbiotic relationship between the roots and a bacterium.

SUMMARY

The heterotrophic mode of nutrition is found in all those organisms which cannot synthesize their organic food from simple molecules like water, carbon dioxide and mineral salts. The heterotrophs, therefore, satisfy part or all of their requirement for carbohydrates, fats, proteins, minerals and vitamins by ingesting plant parts. Much of the food that animals ingest is first broken down into soluble constituents and then used for various life activities. The undigested part of the food is eliminated from the body.

Chemically, the food of all organisms, whether birds, cats, earthworms, fungi or man, consists of carbohydrates, proteins, fats, water, minerals and certain vitamins. In the process of digestion complex molecules of carbohydrates, proteins and fats are broken with the help of enzymes into smaller constituents such as sugars, amino acids, glycerol and fatty acids.

In extracellular digestion the cells pour out enzymes to hydrolyse food. This may occur within a special cavity in the body, such as alimentary canal of animals, or outside the body as in fungi decomposing organic matter. In intracellular digestion the food is hydrolysed within the cells. This mode of nutrition occurs in lower animals like sponges and coelenterates.

The soluble products of the digested food are absorbed into the cytoplasm and used for deriving energy and for building purposes.

Among higher plants too, there are examples of complete or partial heterotrophy. Insectivorous plants like *Drosera* supplement their food supplies by digesting insects by means of highly specialized structures. Others like *Cuscuta* parasitize various hosts through special absorbing devices called haustoria. Most bacteria, and fungi are also either saprophytes or parasites.

QUESTIONS

1. Distinguish between an autotroph and a heterotroph.
2. Mention four chief uses of food to the body.
3. What is a 'balanced' diet? Give a list of the materials that you ate during the last 24 hours, indicating their sources and nutritive values.
4. Discuss which mode of nutrition evolved first on our planet. If your answer is heterotrophy, then how have the present-day heterotrophs become dependent upon the autotrophs?
5. What is a parasite, a saprophyte, and a symbiont?
6. Explain how a ruminant may starve in spite of a filled belly.
7. Why is it advisable to take meals in a pleasant atmosphere?
8. Some people can eat things even when standing on their heads. Why does not the food fall back into the mouth?
9. Deficiency of protein may result in a very slow healing of wounds. Why?
10. Name the vitamins and minerals needed to keep the bones healthy.
11. If you find a good portion of the population of a city suffering from goiter, what possible reasons would you suggest?
12. Which class of food gives the maximum energy per kilogram? Which gives the least?
13. Give details of a balanced vegetarian diet that can be procured at the lowest cost.
14. Name the vitamins, the lack of which may cause the following disorders:
    Nightblindness, rickets, bleeding gums, muscular pains and general laziness.
15. Comment on the statement. 'Food swallowed into the stomach is not yet in the body.'
16. Relate, as though to a junior student, the story of the discovery of vitamins.
17. Name three methods of cooking which may result in the loss of vitamins in the food.

18. How does food move along the alimentary canal? Guess what happens when partly digested food moves in the opposite direction, as in vomiting.

19. Describe in detail all the processes by which the proteins in your breakfast become a part of the muscles in your arms.

20. Keep a complete record of all that you eat during a week. Work out the approximate proportions of the main constituents (carbohydrates, proteins and fats). Are you getting a balanced diet?

21. Comment upon the following advertisement taken from a newspaper: "Rely on milk chocolate. It is a handy, balanced food, besides being a satisfying sweet."

22. Is the costly food served in fashionable hotels more nutritious than the usual food one takes daily at home?

23. Some people advise that water should not be taken with meals. From your knowledge of the process of digestion (remember that it is essentially a hydrolysis of food) what would you recommend?

24. Name an animal that digests its food before taking it into its body.

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CHAPTER 41

Transport and Circulation

WE have said in an earlier chapter that in order to grow or even to stay alive, all living cells must incessantly expend some energy. To enable this, several things must happen concurrently: the cells must be adequately supplied with foodstuffs and oxygen, and the waste products of metabolism must be continuously drained so that they do not poison the system. In small organisms most of the cells are exposed to the environment, and oxygen as well as food can be taken up directly by the process of diffusion. Likewise, the waste products such as carbon dioxide, ammonia and other nitrogenous substances can also be discharged directly into the environment. In the more highly organized forms, however, the surface exposed to the environment is negligible as compared with the total volume of the living tissues. The simple diffusion of substances from the exposed parts to the deeper lying tissues is not adequate for the quick transport of materials. The more advanced forms of life, therefore, have much more elaborate arrangements for this purpose. In higher plants circulation of materials occurs through the intercellular spaces and through water. In higher animals there is usually a body fluid (blood) which is partly or completely enclosed in a system of much branched tubes traversing all the tissues of the body.

TRANSPORT AND CIRCULATION IN PLANTS

Of the four basic things required by plants, namely, carbon dioxide, oxygen, water and mineral salts, the first two enter the plants through the stomata. There are no special breathing organs corresponding to the lungs and gills of animals. This is because of two reasons: first, most plants are extensively branched and possess a large surface area through which sufficient exchange of gases can take place. Secondly, the stomata and lenticels form a very good link between the internal atmosphere (intercellular spaces) of the plant and the outer air. However, water and dissolved minerals gain entry into the plant through the roots. Subsequently they have to be transported through the stem to all of the numerous branches and leaves. Organic foods are prepared in the leaves and have to be supplied to all the non-green parts down to the farthest roots.

Conduction of Water and Minerals

The water taken up through root hairs moves deeper into the root by the process of osmosis until it reaches the vascular

bundles. These consist of two types of tissues, xylem and phloem. The upward conduction of water and the minerals dissolved in it occurs mainly through the xylem. This consists of elongated cells called tracheids (as in ferns and gymnosperms) and long tubular canals called vessels (in angiosperms). Both tracheids and vessels form a continuous conducting system from the roots, through stems, to the veins of the leaves (Fig. 41.1). That the conduction of water and minerals occurs chiefly through the xylem can be shown by a simple experiment. Take two leafy twigs and remove the bark from the lower few centimetres of each. Next, cover the exposed part with hot paraffin wax so as to block the phloem of one and xylem of the other twig (Fig. 41.2). Stand the two twigs with their cut ends dipping in water. You find that the

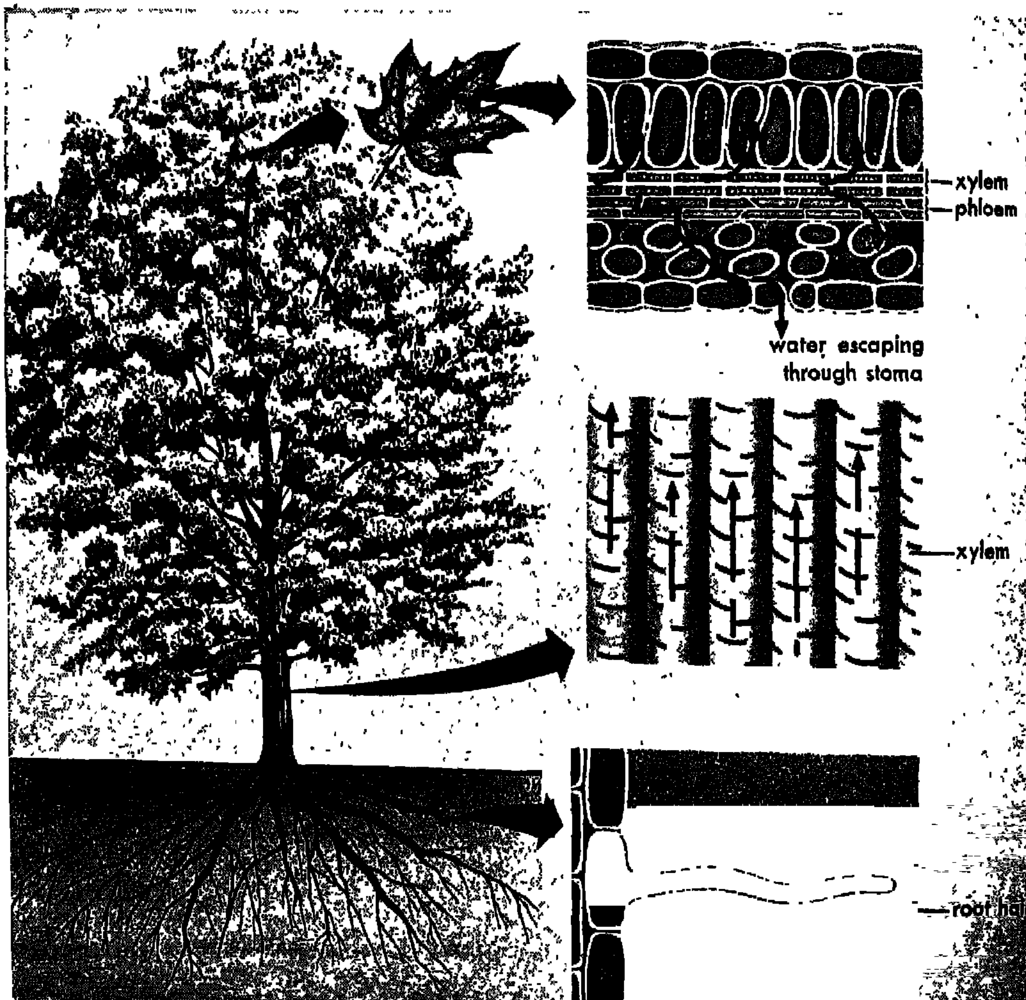


Fig. 41.1. The path of movement of water in a tree. From *BSCS, Biological Science· Molecules to Man*, Houghton Mifflin Company, Boston, 1963.

twig with blocked phloem remains perfectly fresh, but the second (with blocked xylem) wilts after some time.

In the tallest trees, such as the eucalyptus of Australia and redwood of the USA, the water may have to rise as much as 140 metres. If you work out the pressure that would be needed to lift a column of water up a 140 metre tall tree, it would come to about 15 kg per square centimetre, provided there were no frictional force between the water and the walls of the vessels. Moreover, the speed of ascent and the volume of water transported are fantastic. In some trees the water rises at the rate of 45 m per hour, and some desert plants may lift as much as 370 litres of water per day to make up their water loss due to intense heat !

One wonders as to the mechanism which makes the water move up in plants, since they do not have any pumping mechanism like the heart in animals. Several explanations have been proposed; some of these are discussed below.

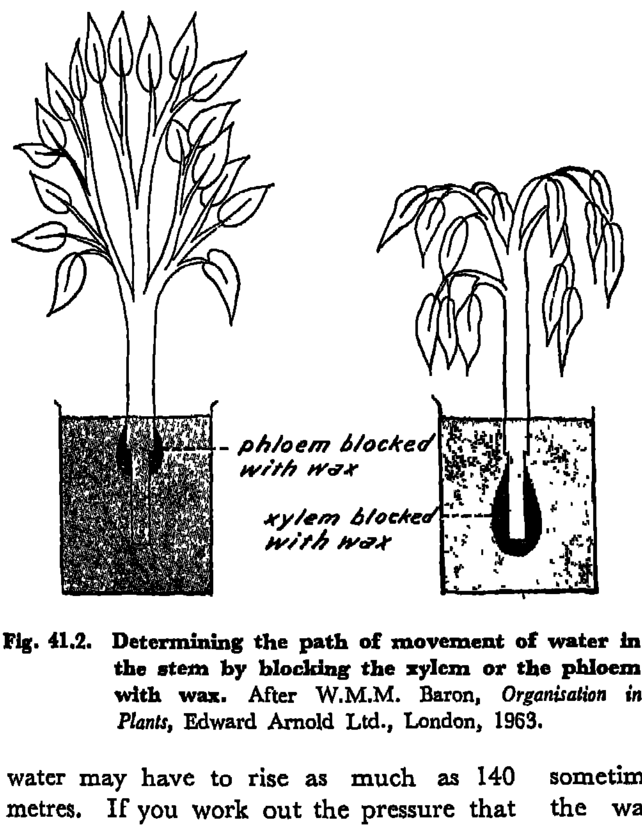


Fig. 41.2. Determining the path of movement of water in the stem by blocking the xylem or the phloem with wax. After W.M.M. Baron, *Organisation in Plants,* Edward Arnold Ltd., London, 1963.

Root pressure theory. When the entire top of a plant is cut off a few centimetres above the soil, sap continues to ooze through the exposed stump for several hours. If a glass tube is attached to the stump by means of a rubber tube, the sap will gradually rise into the tube. By means of a mercury manometer the actual pressure of the sap can be measured (Fig. 41.3). The force causing the flow of sap through the stem is called **root pressure.** Experiments have shown that a single rootlet of tomato exerts a pressure as high as 2–6 kg per square centimetre. This pressure would easily push water to a height of about 65 metres. It must be admitted, however, that most workers find root pressures of a much lower value, and the pressure is sometimes lowest or even absent when the water loss from the plant is the highest. In addition, this force cannot lift water as fast as the sap sometimes rises in the stems. It is therefore suggested that root pressure alone is inadequate in lifting water up in the plants, especially in the very tall trees.

Pulsation theory. Several years ago Sir J.C. Bose, working at Calcutta, suggested that water moves up by a pulsatory movement of the cells. He built an electrical device which on being connected to the stem recorded the alternate expansion and con-

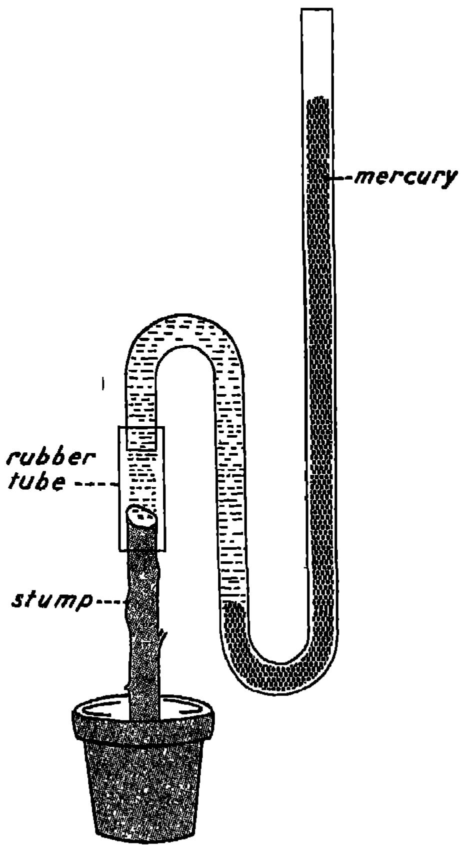


Fig. 41.3. Apparatus to demonstrate root pressure. From J. Bonner and A.W. Galston, *Principles of Plant Physiology*, W.H. Freeman and Company, San Francisco, 1952.

traction of cells. However, his findings have not been confirmed by other workers.

Suction pressure and cohesion theory. Instead of being pushed from below, the water could also be pulled from above. This theory rests on the important property of cohesion of the water molecules. **Cohesion** is the mutual attraction between the molecules of a substance. It is also known as tensile strength or resistance to breaking when pulled apart. The cohesive force between water molecules is very large. That is to say, if there is a continuous column of water along a thin, air tight tube, it has a great tensile strength and can withstand a pull of 350 kilograms per square centimetre. The tensile strength of plant sap is slightly less than that of pure water, but is still quite adequate to withstand the pull required to raise water to the top of the tallest trees. It is all right, then, to assume that the sap can be pulled up. But what pulls the water column itself? It is suggested that the mesophyll cells of the leaves contain large amounts of sugars produced during photosynthesis. When water is lost from the mesophyll cells the concentration of dissolved materials becomes high and that of water becomes low. A suction force is created which causes the water to move from the xylem by osmosis. The entire water column, which is continuous from the leaves down to the roots, is lifted in much the same way as a rope can be pulled up through a tube (Fig. 41.4). The suction pressure, generated by the loss of water either due to transpiration or due to its use in growth and photosynthesis, is of a sufficient magnitude to cause the water column to rise to the top of the tallest trees.

Transport of Organic Substances

While water and minerals are conducted through the xylem, organic materials are translocated through the phloem. This is elegantly shown by **ringing** experiments of the type shown in figure 41.5. If a ringed stem is left for some months, the bark above the ring swells up. This is due to the accumulation of carbohydrates, amino acids and other organic compounds whose downward movement is now blocked. Although the translocation of food materials is definitely known to occur through the sieve tubes of the phloem, the exact mechanism of transport is not at all understood. One

thing is, however, quite clear that the simple diffusion of solutes would not be adequate.

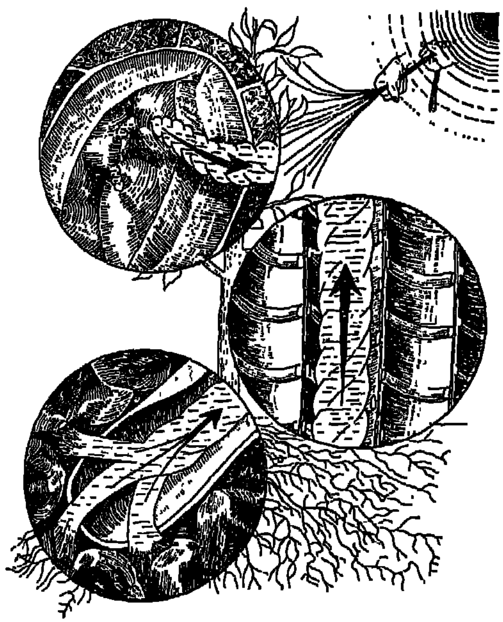
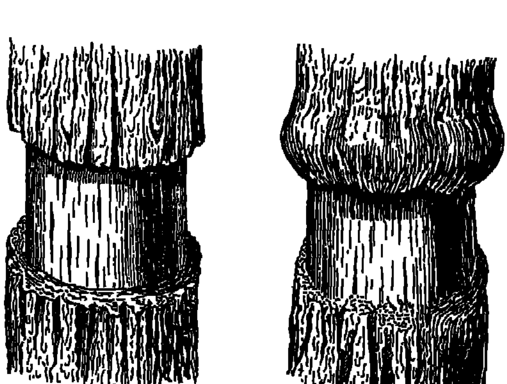


Fig. 41.4. Diagrammatic representation of the transpiration-cohesion-tension theory for the ascent of sap. The evaporation of water through the stomata from the leaf parenchyma cells results in a tension on the water column in the xylem. This tension is transmitted to the absorbing cells of the roots. From J. Bonner and A.W. Galston, *Principles of Plant Physiology*, W.H. Freeman and Company, San Francisco, 1952.



TRANSPORT AND CIRCULATION IN ANIMALS

In the small multicellular animals the transport of gases and other substances is not much of a problem. Consider, for instance, the hydra. It is composed of just two cell layers. Oxygen, carbon dioxide and water can easily enter or leave the cells through their exposed surface. The food is ingested by some special cells of the inner layer but the other cells can easily receive the digested food by diffusion. However, when the animal is of a larger size, only a small fraction of its total surface can be in direct touch with the environment. The distribution of materials by diffusion alone is then inadequate. The deep-seated cells may easily become starved (due to lack of food), suffocated (due to lack of oxygen) and even poisoned (by the accumulated excretory products). The larger animals have two ways of transporting materials. The first is to have an increased surface area to promote active diffusion, as seen in the flatworms. Recall the structure of a liver-fluke. The body is thin and flattened like a leaf. Enough air can diffuse through the large exposed surface. The alimentary canal, excretory organs as well as reproductive organs are extensively branched. This means that all the cells of the body, no matter to which system they belong, are in close contact with each other, and transport of substances can still occur by simple diffusion.

Fig. 41.5. Girdling of a woody shoot by removal of a ring of bark, leaving the xylem intact. Left, immediately after removal of the bark; right, a few weeks later. From J. Bonner and A.W. Galston, *Principles of Plant Physiology*, W.H. Freeman and Company, San Francisco, 1952.

Other animals have a circulating fluid, the blood, that carries materials from one part of the body to another. In the roundworms the blood simply fills the space around the intestine and other small spaces in the tissues of the body. In the earthworm and in animals of all higher phyla the blood flows partly or wholly in a system of tubes.

You are perhaps accustomed to visualize blood as a red fluid, but this is not so in all animals. In most insects the blood is colourless; in some annelids it is green and in many molluscs it is blue (at least when oxidized). We shall restrict our discussion of circulation mainly to the vertebrates, especially man. The human circulatory system consists of (1) the blood, (2) the arteries, (3) the veins and (4) the heart. The arteries carry the oxygenated blood from the heart into various organs. The veins bring back the deoxygenated blood loaded with carbon dioxide.

Because of the great attraction of haemoglobin for oxygen, large quantities of oxygen get bound to it. This is a far more efficient way of carrying this gas than if it were to be carried by water in the plasma. In an average human being about a litre of oxygen is dissolved in the blood. However, to hold the same amount of oxygen without haemoglobin human beings would require 300 litres of blood instead of just five! The blood of the earthworm which has no haemoglobin contains only 0.3 per cent oxygen.

Haemoglobin has the unique capacity of taking up a lot of oxygen and giving up carbon dioxide wherever oxygen is abundant, as in the lungs immediately after the air is inhaled. In regions where oxygen concentration is low—as in the areas where the capillaries branch among tissue cells—haemoglobin gives up the oxygen and soaks up carbon dioxide to be released later on in the lungs.

The basic fact of blood circulation was first discovered about 300 years ago by an English doctor, named William Harvey. He noted that blood leaves the heart through the arteries and somehow comes back to it through the veins. He was also the first to recognize the circulation of blood in a closed circuit. However, he did not know how the arteries are connected to the veins. Malpighi, an Italian scientist, observed this a few years later with the help of a microscope. We know now, of course, that the arteries branch into arterioles and then into still smaller vessels called capillaries. Several capillaries join to form venules which unite to form veins. Thus blood flows from the artery to the vein through the capillaries. The capillaries are very richly distributed, reaching the neighbourhood of practically every cell. You can form an idea of

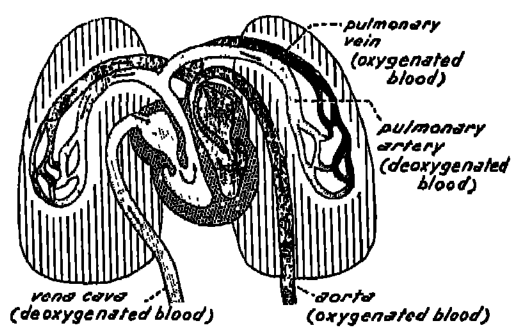


Fig. 41.6. Diagram of the course of circulation of blood through the heart and lungs. From P. B. Weisz, *Biology*, McGraw-Hill Book Company, Inc., New York, 1963.

their abundance from the estimate that their spread in an average person would form a tube some 100,000 to 150,000 kilometres long. The diameter of a capillary is so small that blood cells must move slowly and in a single file. Due to this slow movement of corpuscles, the blood can effectively do its job of delivering the load of nutrients and oxygen to the cells, and of removing

waste products from them. Just how does the blood discharge its function? All the details are not known but an outline of what is understood is as follows. The nutrient materials in solution seep out of the capillary walls into the lymphatic fluid that bathes all the cells. Thus the blood constantly replenishes the lymph from which the cells can derive their nourishment. Due to respiration, the oxygen content of the cells goes down. In an oxygen-poor atmosphere the oxyhaemoglobin of the blood delivers its oxygen to the cells and soaks up carbon dioxide from them.

The veins from the posterior part of the body unite to form the posterior vena cava and those from the anterior region form the anterior vena cava. These large veins pour blood into the right auricle. When this chamber is full, the valves on its floor open and let the blood fill into the right ventricle which pumps it into the lungs. After oxygenation the blood gets back into the left auricle and fills into the left ventricle from where it is pumped to the various parts of the body through the arteries (Fig. 41.6). Thus throughout its course in the body the blood remains enclosed in the tubes—arteries, capillaries, veins and heart. Such a vascular system is termed **closed circulatory system** and is found in all vertebrates and some invertebrates such as earthworm and octopus. However, in insects and snails, the heart pumps blood into a set of arteries from where it flows into the large body spaces and bathes the various organs. In snails, the blood eventually enters a set of veins which open into the heart. In insects, the blood enters the heart directly from the body spaces. This is called an **incomplete vascular system** or **open circulatory system.**

As compared to the red blood cells, the white blood cells are much less abundant. For every 600 red cells there is only one white cell. Yet these cells play a very important role in defence of the body against bacterial or viral attack. If bacteria and viruses enter the body through a wound, the white blood cells immediately gather near the wound, and engulf and digest the invading organisms. This 'battle' often results in the formation of a thick, yellowish fluid known as pus. It contains lymph, dead bacteria and white cells (Fig. 41.7). The struggle between the white blood cells and bacteria often results in the release of toxins which cause fever.

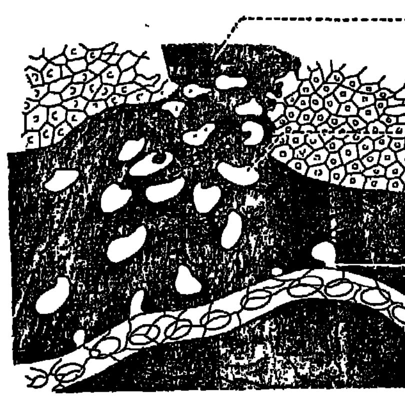


Fig. 41.7. Formation of pus. Whenever there is an infection in the body, the white blood cells gather in the area of infection and begin to engulf the bacteria. After T.J. Moon, J.H. Otto and T. Towle, *Modern Biology*, Holt, Rinehart and Winston, Inc., New York, 1960.

The third kind of blood cells called blood platelets are much smaller than the red blood cells. They help in the clotting of blood. The mechanism of clotting has already been described in Section III.

Circulatory Disorders

You must have often heard people complaining of fatigue. Such individuals do not

The chemical basis of the action of nerves was discovered by Otto Loewi of the USA. He kept the hearts of two frogs in two dishes, and left the vagus nerve of one heart intact, but cut off that of the other (Fig. 41.9 A and B). When he stimulated the vagus of the heart A, he found that its rate of beating gradually declined. But surprisingly, when he transferred some of the fluid from the first dish into the other, the beating of the heart B also slowed down. On the contrary, when the nerve from the spinal cord was stimulated, the heart beat was accelerated. The substance liberated as the result of the stimulation of the vagus nerve was later identified as acetylcholine whereas that liberated from the spinal nerve was found to be adrenaline.

The regulation of the heart beat in the snail is also controlled by nerves. However, in insects the heart muscle does not have the property of beating automatically. In these animals the heart beat is both initiated and regulated by nerves, and the heart stops beating as soon as the nerves are cut. In vertebrates the initiation of the heart beat is independent of the nerves, and the latter control only the frequency of heart beat.

SUMMARY

In plants the roots absorb water and salts which are transported through the xylem to the leaves and other aerial parts. Organic food synthesized in the leaves is transported to various parts of the plant through the phloem. Oxygen and carbon dioxide, on the other hand, diffuse to various parts through the stomata, lenticels and cuticle.

In higher animals the circulatory system consists of the blood, arteries, veins and heart. The heart pumps the blood with a certain force so that it circulates rapidly in the vessels. The blood of most animals contains a respiratory pigment called haemoglobin which temporarily combines with oxygen and releases it into the respiring cells. Haemoglobin also removes carbon dioxide from the cells. The blood also performs several other functions like the transport of food and hormones, the removal of waste matter, and the maintenance of a constant temperature of the body.

QUESTIONS

1. Sketch a diagram to show the direction of flow of minerals, water, carbon dioxide and glucose in a plant.

2. Explain why the blood of earthworm is less efficient as an oxygen carrier than that of man.

3. Describe the events that occur while blood flows through a capillary.

4. What is the total volume of blood in your body? How will the various physiological processes be affected if the body loses half the total volume of blood?

5. In what way does the blood entering the kidney differ from that leaving the kidney?

6. Describe some experiments to demonstrate the flow of sap through the xylem and of organic food through the phloem.

7. What is the difference between the modes of circulation of water in animals and plants?

8. How does water move to the top of a tree?

9. Often you find some whitish fluid in wounds. What is it and how is it formed?

10. What is meant by 'heart attack'? Mention at least three common defects of the circulatory system which lead to heart attack.

11. What is the difference between an open circulation and closed circulation? Name two animals that have an open type of circulation.

12. What is the advantage of having a pigment like haemoglobin in the blood? Do you know of any animal whose blood does not have any pigment or has a pigment other than haemoglobin?

13. Does it make any difference to have the haemoglobin in the corpuscles rather than in the plasma? Explain.

14. The veins have neither elastic walls nor any pulsating movement. How does the blood then return from, say, your legs to the heart?

15. How is blood useful in combating germs?

16. In which part of the body are the red blood cells formed? What part filters out the dead and worn out corpuscles?

17. Describe in detail what actually happens when you get a painful swelling in your armpit.

18. Why do doctors frequently make a red blood count of such patients who are pale and feel tired very soon?

19. How can you determine the rate of flow of blood in your body?

20. It is easy to see that the blood moves in the body, but how will you demonstrate that it does actually circulate?

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CHAPTER 42

Respiration and Provision of Energy

RESPIRATION is one of the important criteria of life. We all respire incessantly as long as we live; the cessation of respiration is a sure sign of death.

Outwardly, respiration involves the processes of **expiration** and **inspiration**, i.e. the exhalation of impure air containing carbon dioxide, and the inhalation of oxygen-rich 'pure air' from the atmosphere. This phenomenon is commonly called breathing. However, breathing is merely a mechanical process. The essential thing in respiration is the release of energy through the chemical oxidation of food. When a foodstuff, such as glucose, is broken down in the cell, the atoms of hydrogen and carbon present in it combine with the oxygen of the air, producing molecules of carbon dioxide, water and a lot of energy (673 Cal per mole of glucose) which the cell utilizes for various purposes.

Organs of Respiration

Organisms possess different types of structures for obtaining oxygen from the environment. In the unicellular and the smaller of the multicellular organisms, all the cells take up oxygen directly from the surrounding air or water, and pass out carbon dioxide in a similar way. The oxygen content of the air is about 21 per cent, whereas that of water is only 0.5 per cent at 37C.

In most higher plants the exchange of gases occurs by simple diffusion through stomata, lenticels and extensive intercellular spaces. In chlorophyllous tissues photosynthesis normally goes on at a much faster rate than respiration; hence there is surplus oxygen during the day. At night a green plant can draw on for its respiration the oxygen present in the intercellular spaces.

As contrasted with plants, animals are far more compactly built. Furthermore, weight for weight animal tissues are metabolically more active. Hence, the more advanced groups of animals have evolved special organs of respiration. These are of the four main types: (a) skin, (b) gills, (c) tracheae, and (d) lungs (Fig. 42.1).

Skin. Many animals like the leech and the earthworm have a smooth and moist skin, richly supplied with blood. The exchange of gases occurs readily through the entire surface of the body. In frogs and other amphibians the skin serves the same

purpose, and during hibernation it is the main organ of respiration.

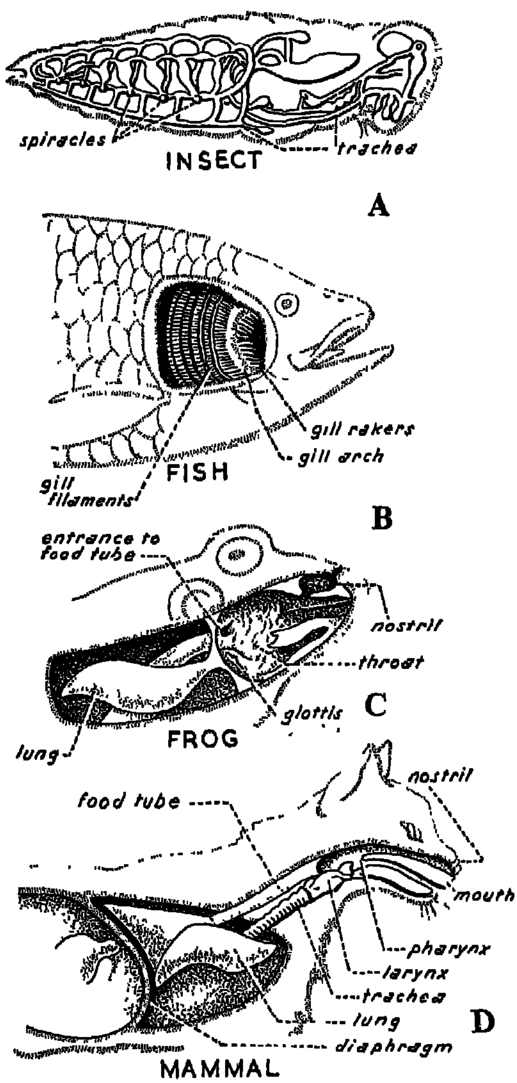

Fig. 42.1. Different types of respiratory organs found in animals. A. Tracheae of an insect. B. Gills of a fish. C. Lung of a frog. D. Lung of a mammal. After C. Gramet and J. Mandel, *Biology Serving You*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1958.

Gills. You have already learnt about the gills of fish. They are richly supplied with blood, and readily absorb oxygen from the water. These structures, also present in prawn, crab and freshwater mussel (a mollusc), are formed from the extensions of the body wall. The surface of the gills is greatly increased by the presence of filaments. The oxygen absorbed through the surface is taken up by the blood, and the carbon dioxide in the blood is given out into the water. Gills are, however, unsuitable for respiration in air.

Tracheae and lungs. You would recall the branched respiratory tubes or tracheae of insects. These open on the surface of the body through small pores or spiracles, and their branches (the tracheoles) penetrate the tissues. The movement of the air from the outside to the inside occurs by up and down movements of the body. The oxygen dissolves in the body fluid and then diffuses into the cells. While such direct supply of oxygen is satisfactory for insects, it is inadequate for animals of larger size and all terrestrial vertebrates. They, therefore, have more elaborate mechanism, the lungs. Some sac-like structures resembling lungs are also present in certain invertebrates such as the pond snails which live partly on land and partly in water.

Mechanism of Respiration in Man

Our lungs lie in the chest cavity which is bound by the ribs and the diaphragm (Fig. 28.37, p. 319). By contraction and expansion of the muscles attached to the ribs and the diaphragm, the lungs are made to contract and expand alternately. These movements cause the inhalation and exhalation of air. The volume of air that moves

in or goes out in a single stroke of respiration is called the **tidal volume** and is about 500 ml in man. This volume can be determined by a simple experiment illustrated in figure 42.2. Normally, we breathe about 15 times every minute. However, this value is frequently exceeded during running or other exercises. On the other hand, during sleep this value is much lower. The rate of breathing is regulated by the nerves which originate from the respiratory centre in the brain, and supply the muscles of the diaphragm and the ribs. The respiratory centre is amply supplied with blood, and is very sensitive to changes in the concentration of carbon dioxide. If the carbon dioxide content of blood increases, the centre sends stimuli to the concerned muscles for deeper and faster respiration. Similarly, there are centres on the aorta and the carotid artery which are sensitive to oxygen deficiency and which stimulate respiration when the oxygen content of the blood becomes low.

A high concentration of carbon dioxide is harmful to the tissues because it combines with water to form carbonic acid, and makes the blood acidic. It is not surprising, therefore, that the cells of the body can tolerate the lack of oxygen for some time, but they cannot tolerate an increase in the concentration of carbon dioxide. We can stop breathing for one or two minutes, but during this period so much carbon dioxide accumulates and its effect on the respiratory centre is so great that we cannot hold our breath any longer.

Exchange of gases in the lungs. The alveoli of the lungs are supplied with blood by the pulmonary artery which branches into numerous capillaries (Fig. 42.3). The walls of the alveoli and capillaries are so thin that oxygen from the alveoli diffuses into the

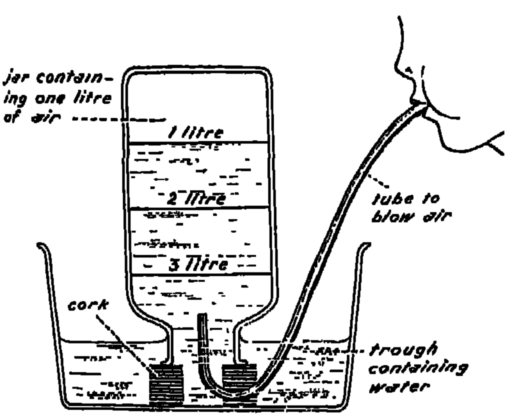

Fig. 42.2. Apparatus for measuring the volume of exhaled air. One full breath blown into the bottle will put in about a litre of air, but with practice the volume may be increased. After E.T. Smith and L. Lisonbee, *Your Biology*, Harcourt, Brace & World, Inc., New York, 1962.

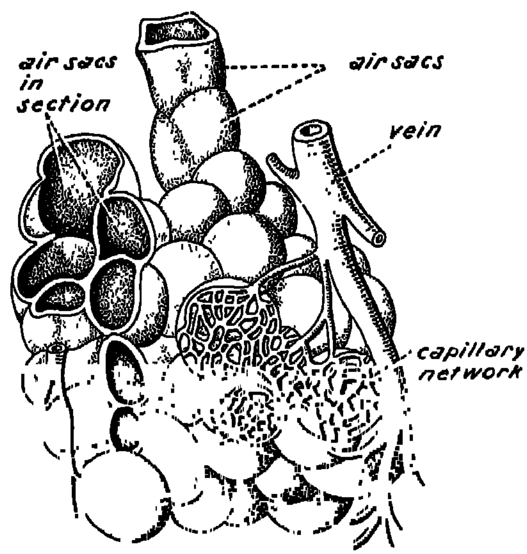

Fig. 42.3. A part of lung highly magnified to show the alveoli. In these air sacs the blood capillaries release the carbon dioxide and pick up oxygen. After E. Kroeber, W.H. Wolff and R.L. Weaver, *Biology*, D. C. Heath and Company, Boston, 1960.

capillaries which carry blood deficient in oxygen. The approximate percentages of oxygen and carbon dioxide in the inhaled and exhaled air are shown in the following Table.

Gases	Inhaled air	Exhaled air
Oxygen	21%	16%
Carbon dioxide	0.03%	4%

Respiratory Carrier

As mentioned in the last chapter, one of the most important functions of the blood is to transport oxygen to different organs. The amount of dissolved oxygen that can be held by the plasma is only about 0.3 per cent. This concentration is too low to meet the requirements of the cells. Hence, many invertebrates and all vertebrates have a special **respiratory carrier** or pigment called haemoglobin (Hb), which can bind oxygen temporarily and thus increase the oxygen carrying capacity of blood nearly 70 times. In man 100 ml of blood contains 20 ml of oxygen most of which is bound to haemoglobin.

As soon as the oxygen from the lungs enters the blood it combines with haemoglobin forming oxyhaemoglobin (HbO_2) in the red blood cells which are then pumped by the heart to various organs through the arteries. The arteries, as you already know, divide into fine capillaries. Here the oxyhaemoglobin breaks up into haemoglobin and oxygen. Since the concentration of oxygen in the surrounding cells is less than that in the blood, the oxygen of the blood diffuses through the capillaries into the cells. At the same time carbon dioxide which is present in higher concentration in the cells, diffuses into the blood and forms sodium bicarbonate. The deoxygenated blood, rich in sodium bicarbonate, flows into the veins and ultimately reaches the lungs. Here the sodium bicarbonate decomposes and releases its carbon dioxide which now diffuses into the lung cavity. At the same time, haemoglobin captures the oxygen to continue the cycle.

Biochemistry of Respiration

You have seen above that animals have elaborate mechanisms for bringing oxygen to the cells. The main use of oxygen in the cell is the oxidation of food substances. Among these, glucose is the commonest. Its oxidation proceeds as is shown in the following equation:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \longrightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{energy}}{673\ \text{Cal}}$$

We shall not concern ourselves with the detailed biochemistry of the breakdown of glucose as this involves about 30-40 steps. However, these steps can be studied under two major groups: (1) **glycolysis**, and (2) **Krebs cycle** or **citric acid cycle** (Fig. 42.4). Glycolysis includes those steps in which each 6-carbon glucose molecule is broken down to two 3-carbon pyruvic acid molecules. These steps can go on even in the absence of oxygen. In the Krebs cycle—named after its discoverer, Hans Adolph Krebs—each of the pyruvic acid molecules is broken down to water and carbon dioxide. The Krebs cycle requires large quantities of oxygen and therefore operates only in aerobic organisms.

It is believed that the oxidation of each molecule of glucose leads to the production of some 60 ATP molecules. Of these, two are produced during glycolysis and the rest during the Krebs cycle. All the enzymes

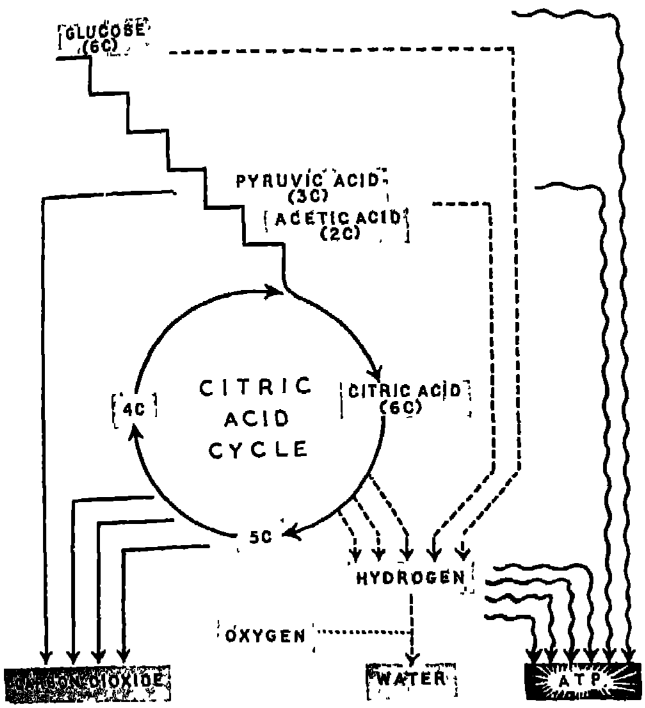

Fig. 42.4. In both aerobic and anaerobic respiration pyruvic acid is formed from glucose. In the presence of oxygen pyruvic acid is broken down to carbon dioxide and water, whereas in the absence of oxygen it is incompletely oxidized to form carbon dioxide and alcohol or lactic acid. A much larger amount of energy (ATP) is obtained under conditions of aerobic respiration. Courtesy of the Department of Botany, University of Delhi.

connected with the Krebs cycle are packed compactly in the mitochondria which can thus be thought of as the 'powerhouses' of the cell.

You may well wonder why the oxidation of glucose cannot be carried out in one step. Well, if all the energy of the glucose were released as in a log-fire, it would mostly be wasted. Also, the heat evolved would be so great that it would burn the body. Therefore, Nature has devised an ingenious method by which sugar is oxidized, stepwise, each step leading to the liberation of a small amount of energy. These little 'packets' of energy are immediately stored or

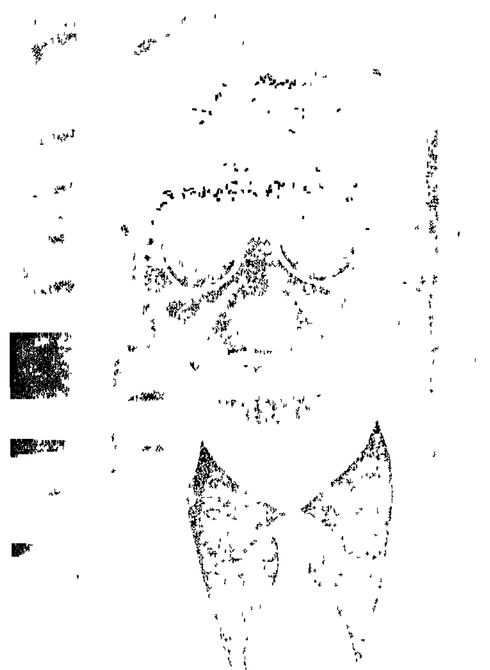

Fig. 42.5. The British scientist, H. A. Krebs, who was awarded the Nobel Prize for finding out a metabolic cycle in respiration. Courtesy of the British Information Services, New Delhi.

trapped by molecules of ADP (adenosine diphosphate) which on receiving the energy pick up a phosphate ion and become changed to ATP (adenosine triphosphate). The ATP molecules can readily deliver their energy whenever needed. In this process ATP molecules become ADP molecules, but these can again trap more energy (Fig. 42.6). Other carbohydrates, fats and proteins can also be oxidized to produce ATP which is essential for all activities.

a part of their energy requirement can be met from this source. However, the non-green parts like roots, fruits and stems derive their energy exclusively from respiration.

Figure 42.7 shows how respiration can be demonstrated in plants. The various parts of the plants differ greatly in their respiratory activity. The highest rates of respiration are found in the growing parts like root and shoot apices and germinating seeds.

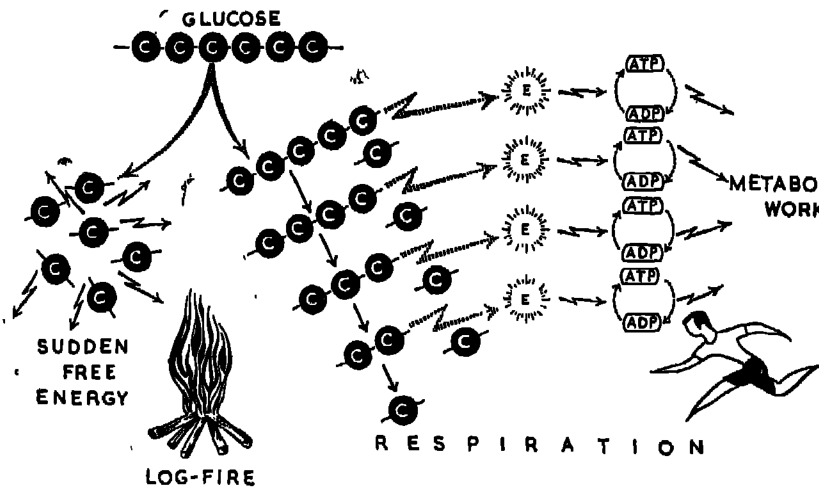

Fig. 42.6. Comparison between log-fire and respiration. In the log-fire, oxidation is very rapid, yielding sudden, free energy in the form of heat and light. In the living organism, too, oxidation is going on but not so rapidly; the bonds of organic molecules are broken down one at a time, yielding energy gradually. Courtesy of the Department of Botany, University of Delhi.

Respiration in Plants

The chemical steps through which glucose is broken down in plants are the same as in animals. Even the enzymes are the same. However, on account of the 'open construction' of the plant body an oxygen carrier such as haemoglobin is unnecessary. Green plants also have the unique power of generating ATP through photosynthesis so that

Anaerobic Respiration

In the preceding pages we have been discussing the mechanism of **aerobic respiration** in which the substrate is oxidized in the presence of oxygen, to water and carbon dioxide—the ultimate products of respiration.

However, respiration can also occur in the absence of oxygen. You can verify this by setting up an experiment as shown

in figure 42.8. Since oxygen is not available to the seeds, the Krebs cycle cannot operate, and a complete oxidation of glucose does not occur. Instead, intermediate products like ethyl alcohol, lactic acid and butyric acid are produced in different organisms. Respiration in the absence of oxygen is said to be **anaerobic respiration** or **fermentation.** Its occurrence is indirectly valuable to man in many ways.

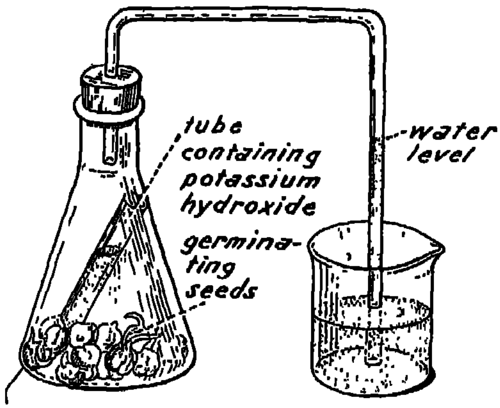

Fig 42.7. Apparatus to demonstrate respiration of seedlings. The Carbon dioxide evolved is absorbed by potassium hydroxide in the tube. Owing to the partial vacuum created in the flask, the level of water in the side tube rises. Courtesy of the Department of Botany, University of Delhi.

One of the commonest organisms which can respire under anaerobic conditions is the yeast (*Saccharomyces*). In this, glucose is broken down in the following manner:

$C_6H_{12}O_6$	$\longrightarrow$	$2\ CO_2$ +	$2C_2H_5OH$
glucose	enzymes in yeast cells	carbon dioxide	alcohol

Many industries, such as those engaged in the making of wine and bread are dependent upon fermentation by yeasts. The common curd or 'dahi' is also a product of fermentation in which the lactic acid bacteria break milk sugar into lactic acid. Fermentation is also of much importance in the making of cheese. In this process several species of *Aspergillus* and *Penicillium* are used to bring about the necessary reactions.

In animals too there are conditions under which anaerobic respiration occurs. For instance, when muscles are over-worked, as during running or jumping over a considerable period, there is an accumulation of lactic acid due to anaeorbic respiration.

However, in general, neither animals nor plants can survive indefinitely by anaerobic respiration alone. Not only the energy released is less, but also the accumulation of large amounts of the products of fermentation like lactic acid and ethyl alcohol is toxic to cells. This explains why most, if not all, higher organisms are aerobic.

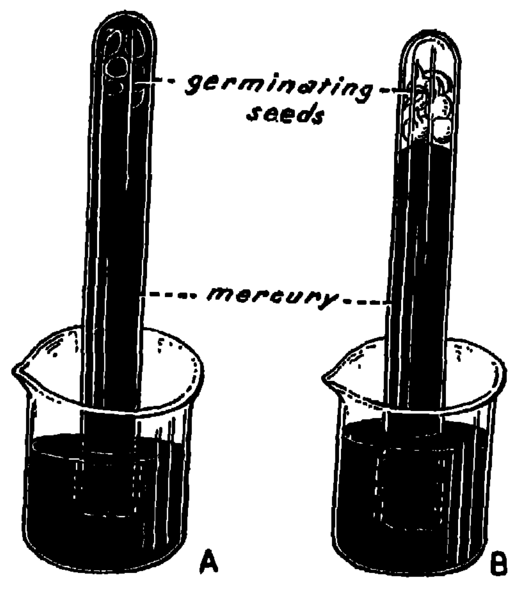

Fig. 42.8. Experiment to demonstrate anaerobic respiration. A. At the commencement of the experiment. B. After a few hours; the carbon dioxide evolved during respiration pushes down the level of the mercury. Courtesy of the Department of Botany, University of Delhi.

SUMMARY

Respiration is a vital process for all living organisms. It enables them to release the chemical energy contained in the food in a form suitable for use in various functions of life. Most commonly this energy is mobilized in the form of ATP which may readily move into the cells whenever required. In the process of release of energy ATP breaks down to ADP and inorganic phosphate.

The primary source of energy in all living organisms is sunlight. This energy is trapped by green plants and is used in the synthesis of various organic molecules which serve as the food of all plants and animals. The organic molecules are broken down to liberate the energy needed for various functions. In aerobic respiration the breakdown occurs in the presence of oxygen, whereas in anaerobic respiration it takes place in the absence of oxygen. The energy derived in the aerobic process is much greater.

Since the energy produced in the presence of oxygen is more, all free-living animals have devices to obtain oxygen. In the multicellular animals oxygen is brought in from outside air or water with the help of the respiratory organs, and is then transported to the tissues through the blood. Plants do not have any special devices or organs for respiration. Enough oxygen is supplied to their cells by diffusion through stomata and intercellular spaces.

QUESTIONS

1. Why is aerobic respiration more efficient than anaerobic respiration?

2. Which type of food has the greatest energy value per unit weight, and why?

3. What is the difference in the composition of the inhaled and exhaled air?

4. Why do you breathe faster while and after running?

5. What are the different types of respiratory structures found in the animals studied by you?

6. Why do mountaineers require oxygen masks when they go higher than 6,000 metres?

7. Do you think that the dry seeds of vegetables and season flowers, as sold in the market, carry on respiration? If your answer is no, does it

mean that they are dead? How do they come to life when sown in the soil?

8. Name two animals which may be found living under anaerobic conditions.

9. Why do physicians advise out-of-door exercises?

10. Why do most fruits kept in the refrigerator remain fresh for a longer period than those kept in a cup-board?

11. How will you prove that one or the other form of energy is liberated when seeds respire? What precautions would you take to perform this experiment successfully?

12. When jams in sealed bottles rot, the lids sometimes blow off. Has it anything to do with respiration?

13. Explain how the blood supplies oxygen to the cells and removes carbon dioxide from them.

14. Think of two conditions under which artificial respiration must be arranged for the patients.

15. How do insects differ from other animals in their mode of supplying oxygen to their body cells?

16. State clearly what happens when a person dies as the result of his failure to breathe for several minutes.

17. An experimenter found that under certain conditions the plants neither liberated oxygen nor took in carbon dioxide. Suggest the possible reasons for these results.

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CHAPTER 43

Excretion

IN the bodies of all living organisms many unwanted by-products are formed as the result of continuous syntheses and breakdown of materials going on in the cells, all the time. Some of these by-products, or waste materials, may become toxic if they accumulate beyond a certain concentration. An important requisite for the continuation of life, therefore, is ridding the body of wastes and accessory matter. The process by which the cellular wastes are disposed of is called excretion; and the organs concerned with this function, excretory organs.

The most important excretory products in the cell are carbon dioxide and ammonia (Fig. 43·1). We have already dealt with the production and elimination of carbon dioxide in Chapter 42 on respiration. We shall now concern ourselves with the origin and disposal

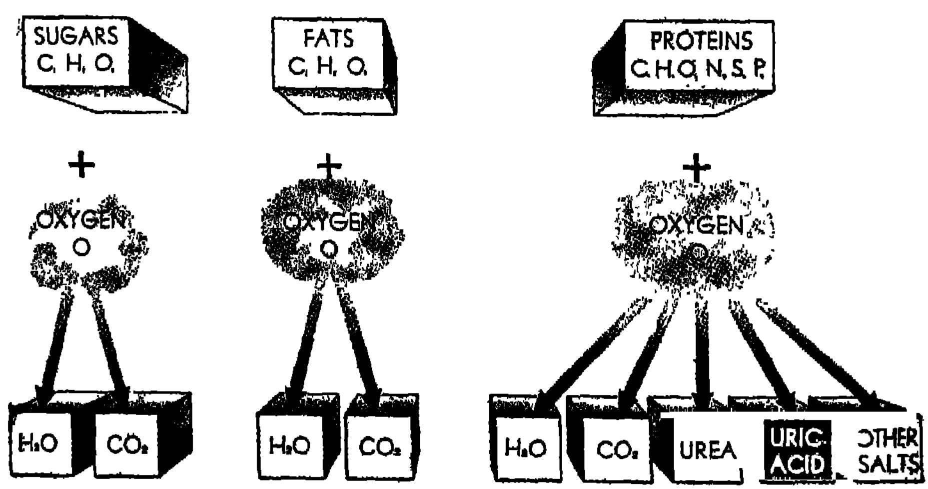

Fig. 43.1. The waste products formed when sugars, fats and proteins are oxidized. From E. Kroeber, W.H. Wolff and R.L. Weaver, *Biology*, D.C. Heath and Company, Boston, 1960.

of ammonia as well as other nitrogenous wastes.

Although proteins are very useful compounds in plants as well as animals, yet all of their hydrolytic products cannot be reused in the synthesis of cellular components. The unused parts are broken down into simpler compounds and excreted from the body. Moreover, certain types of proteins that our tissues needed at an earlier stage of growth may not be required any longer. Besides, the composition of the proteins that we ingest is not quite the same as of those required by the cells of our body. The dietary protein, for example, may contain an excess of certain amino acids which must be either converted into more appropriate types or degraded to ammonia, urea, or uric acid for eventual elimination from the body.

Excretion in Plants

Plants have a unique method of dealing with their waste products. Often they simply use them in the synthesis of foodstuffs. Thus, ammonia formed by the breaking down of proteins and other nitrogenous compounds is utilized by plants for the synthesis of new compounds. Therefore, it is only very rarely that plants have any ammonia left over from the breakdown processes, and they have no special device for its excretion.

Normally plants can tolerate considerable variation in the concentration of salts, but sometimes excess salts are deposited as insoluble crystals in the cells. For example, calcium becomes precipitated in the form of crystals of calcium carbonate or calcium oxalate. These substances are harmful only when they are dissolved in the cell sap, otherwise they are quite harmless.

Appreciable quantities of mineral salts and organic compounds like sugars, amino acids and even proteins are, however, known to be excreted from the roots. Maize roots, for example, secrete large quantities of invertase (the enzyme that converts sucrose into glucose and fructose). Some of the excreted substances, such as the hydrolytic enzymes, may help digest complex materials in the soil and thus facilitate their absorption by the plant. However, it might well be that by this process plants simply get rid of some waste materials.

Excretion in Animals

In animals only a small amount of the total ammonia produced in the cells is used in the synthesis of amino acids. The greater part of ammonia remains unused and is excreted as such or is first converted into urea and uric acid.

In the small aquatic forms like *Amoeba*, *Paramecium*, *Hydra* and sponges, ammonia can diffuse into water directly from the cells in which it is produced. In the larger animals the direct diffusion of these substances to the external medium is too slow to drain them without letting them accumulate in dangerous concentrations. They, therefore, have specialized organs for carrying out this process. The annelids (earthworms and leeches) have tubular structures called **nephridia** which open into the body cavity. They filter out the urea from the body fluid, and excrete it through small openings on the body wall. The snails, which live partly on land and partly in water, also have nephridia for the excretion of urea. The insects excrete their nitrogenous matter through **malpighian tubules.** However, the most highly organized excretory system is present in the vertebrates. In these the urea and other body wastes (excluding carbon dioxide) are separated from the

useful substances in the kidneys. The liver and the sweat glands also partake to some extent in maintaining the cleanliness of our internal environment. However, before we go into the details of the working of the kidneys and sweat glands, let us first understand why in different organisms different kinds of nitrogenous substances are excreted.

Excretion of ammonia. Ammonia is one of the immediate products of degradation of the amino acids. However, it is extremely toxic and, as mentioned earlier, elimination of nitrogenous wastes in this form is possible only in the simpler aquatic animals from which it can diffuse out quickly without accumulating in the cells in injurious concentrations. Among the vertebrates the fishes and amphibians excrete small amounts of ammonia through their urine.

Excretion of urea. Urea is formed by the combination of ammonia and carbon dioxide. It is less toxic than ammonia, and is the main excretory product in most higher animals which have a limited supply of water, and in which rapid diffusion is impossible. The mammals, amphibians and fishes among the vertebrates; and the earthworms, snails and prawns among the invertebrates, excrete urea through their urine. Although these animals are structurally very different from each other, in all of them the enzymes necessary for the production of urea are the same. Urea is produced mainly in the liver from where it is carried to the kidneys by the blood stream. It is eliminated through the urine.

Excretion of uric acid. Even urea is toxic in high concentrations. Large quantities of water are, therefore, needed to dissolve the excess and to excrete it in the form of urine. The human body requires about one litre of water everyday to wash out urea and to keep its concentration at a non-toxic level. Some reptiles, birds and insects that live in places where there is a scarcity of water, convert ammonia into uric acid. Being almost insoluble in water, it is the least toxic of the nitrogenous wastes and is excreted in solid form. The animals with such a mechanism are able to avoid the loss of water through urine. The uric acid of insects, reptiles and birds is whitish, and accumulates in the rectum from where it passes out along with the faeces. In the reptiles and birds uric acid is formed mostly in the liver and to some extent in the kidney. It is transported with the blood to the renal tubule of the kidney where it is concentrated. Its further concentration occurs in the cloaca in which the urine is stored temporarily. The wall of the cloaca absorbs more water from the urine, allowing only a minimum of water to be wasted.

In insects uric acid is synthesized in fat bodies from where it is poured into the 'blood' or haemolymph. It is absorbed by the walls of the malpighian tubules which lie freely in the 'blood' and open posteriorly into the rectum. The scorpions and spiders also excrete uric acid.

The renal tubules and their functions. In all vertebrates that excrete urea the filtration and final concentration of urea occurs in the kidney. You will recall that each kidney is filled with about a million tiny tubes called renal tubules which extract urea and other waste materials from the blood. One end of each of these tubules enters a duct which collects urine; the other end is shaped like a hollow cup which surrounds a network of capillaries. The blood flows through the capillaries into this cup. In this process the corpuscles, and protein molecules are left in the capillaries, and the clear plasma flows through. However, this filtration is not quite complete; the filtered

blood in the tubules has both essential substances like glucose, salts and amino acids; and non-essential substances like urea. In order that the essential substances may not be lost in the urine, they are reabsorbed into the blood through the cells lining the tubules. The return of these substances is highly selective. The urea, small quantities of uric acid and other waste products are eliminated with the urine, whereas glucose and amino acids are reabsorbed (Fig. 43.2). The mechanism by which this happens is still not completely understood. It cannot be explained by mere diffusion since glucose continues to be transported back to the capillaries even when its concentration in them is higher. Such a transport is probably achieved at the expense of energy obtained from respiration, and is therefore called **active transport**

Composition of Urine

The urine is, in reality, blood from which the essential components (e.g. glucose, red blood cells and serum) have been filtered out. It contains about 95 per cent of water and 5 per cent of waste products of which about half is urea.

The composition of urine of a normal person remains fairly constant. However, when he falls ill, the composition may change according to the type of sickness. For example, the urine normally contains almost no glucose, but sometimes it may have

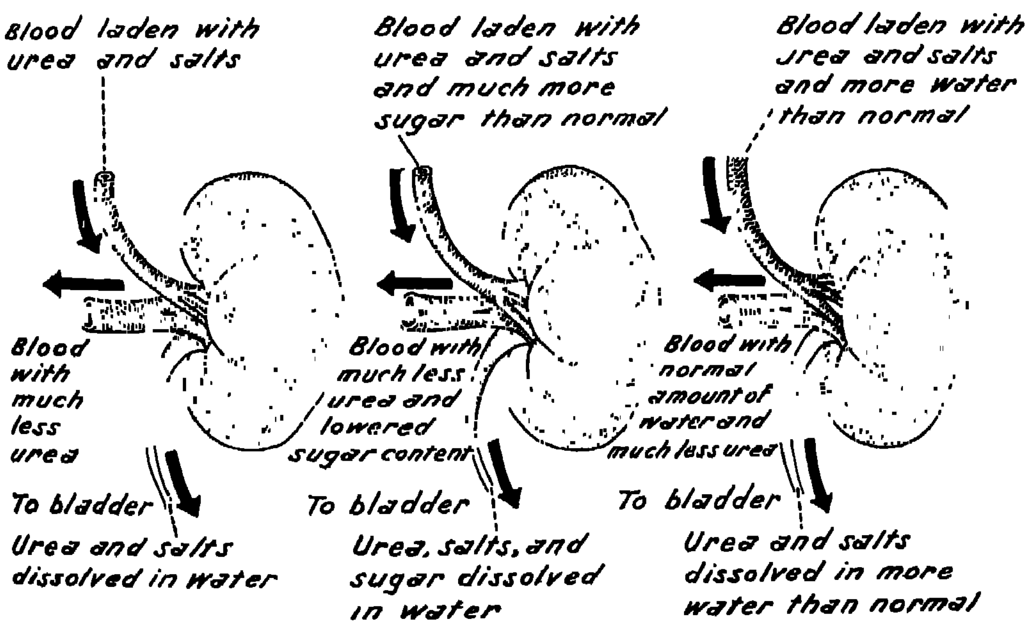

Fig. 43.2. The kidneys remove water, urea and some other organic substances from the blood and keep it normal. After E.T. Smith and L. Lisonbee, *Your Biology*, Harcourt, Brace & World, Inc., New York, 1962.

0.1 per cent or even more. A persistently high level of sugar may be due to a disease called diabetes which interferes with the conversion of the unused sugar into glycogen. The urine sometimes contains blood; this may be due to some damage to the filters of the kidney. By analysing the urine of the patient, the doctor can often diagnose the disease.

Acid-Base Balance in Kidney

If you test a sample of urine with litmus you will find that it is acidic. You have just read that urine is formed from the blood which is slightly alkaline. How can one then explain the acidic nature of urine? This is because acidic substances are being poured continuously into the blood. For example, the muscles pour out lactic acid, and carbon dioxide from all parts of the body combines with the water in the blood to form carbonic acid. For the proper functioning of the enzymes the body must maintain the correct acid-base balance. The kidneys perform an important service in selectively filtering out the acidic substances into the urine. This explains why the urine is invariably acidic.

Care of the Excretory System

The proper functioning of the kidneys is sometimes disrupted following certain ailments such as sore throat and scarlet fever (caused by *Streptococcus* bacteria). Bacterial toxins are carried by the blood to all parts of the body, and the damage to the tiny filters in the kidneys can be so extensive that they lose their power to function and allow the blood cells and albumin to pass out into the urnie. The filters become like an old sieve—full of large holes that allow large pieces of material to slip through. Appearance of blood in urine is a sure sign of damaged kidneys, and a stern warning to consult the doctor. Complete rest must be taken until the kidneys return to the normal state.

Excretion Through Skin

The skin possesses numerous sweat glands each of which is made up of a coiled tube opening to the outside through a pore. The coiled tube is surrounded by numerous capillaries. As the blood flows through the capillaries, a large amount of water, some salts and urea are absorbed by the tube. When it becomes filled up, the waste is eliminated through the pore. Elimination of waste through the sweat glands is called perspiration. The excreted matter or sweat contains about 99 per cent of water.

Excretory Function of Liver

The liver is supplied with oxygen-rich blood by the arteries from the aorta, and with nutrient-rich blood by the vein from the small intestine. Normally, the blood contains 0.1 per cent glucose. If this concentration increases, the liver removes the excess glucose, converts it into glycogen and stores it for future use. When the level of glucose falls below the normal value, glycogen is broken into glucose which dissolves in the blood. Unlike carbohydrates, proteins are not stored in the body. Such of them as can be built up into tissues are used, the rest are broken down. As stated already, this breakdown also occurs in the liver.

SUMMARY

Carbon dioxide and ammonia are the two important waste products of catabolism. Since their accumulation is harmful to the organism they must be excreted. In plants carbon dioxide may be utilized in photosynthesis during daytime. In the dark, it is eliminated by diffusion through the intercellular spaces and stomata. The ammonia produced during the breakdown of proteins is used for the synthesis of amino acids. Thus plants are able to neutralize the harmful effects of carbon dioxide and ammonia by converting them into useful products.

Unlike plants, animals cannot reuse the ammonia and carbon dioxide. In the small aquatic animals these simply diffuse out of the body; there are no special organs for their elimination. The larger animals possess respiratory organs like gills and lungs through which carbon dioxide is eliminated. The nitrogenous waste is excreted by the nephridia in annelids and molluscs; by the malpighian tubules in insects; and by the kidneys in vertebrates.

The form in which the nitrogenous waste is excreted depends on the availability of water to the animal. Animals with a copious supply of water excrete it as uric acid. Among the vertebrates, the fishes, amphibians and mammals excrete urea, whereas the reptiles and birds excrete uric acid. The insects also excrete uric acid.

The kidneys are the chief excretory organs in all vertebrates. They rid the blood of all waste products, and maintain the proper acid-alkali balance. Besides the kidneys, the sweat glands and liver also help the body to maintain a clean internal environment.

QUESTIONS

1. What is meant by excretion? Explain the need for excretion.
2. Compare the excretion of carbon dioxide in animals and plants.
3. What is the source of the ammonia excreted by animals?
4. How is urine formed?
5. Why do doctors examine the urine to diagnose a disease? What do they examine in urine?
6. If one drinks very little water, the volume of his urine decreases. In

what way does it affect his health?

7. Supposing that the kidneys of a person are damaged. Can you predict what is going to happen to him?

8. Name any three organs of excretion in man, and the wastes excreted by each.

9. Excess sugars are stored in the liver in in the form of glycogen. What becomes of the extra proteins?

10. How does urine formation help in maintaining the correct composition of the blood?

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CHAPTER 44

Water Economy

ALL organisms contain plenty of water in their bodies. If you weigh a small plant or an animal and then dry it in an oven, you will find that it loses nearly 70 per cent or more of its weight. You may wonder how and where so much water is contained in an organism. Well, water is not confined to any particular part. The protoplasm itself is made up of nearly 90 per cent of water. The vacuoles in cells are also filled with water.

Water is the medium for all chemical reactions in the cell, and it is also required for the transport of solutes in the body. Furthermore, water is a reactant or an end product in many reactions such as photosynthesis, respiration, digestion, condensation, etc. In plants especially, the various organs keep their form and turgidity due to their high water content.

No wonder, therefore, that life processes come to a standstill if water is not available. Dry seeds, for instance, show little activity and germinate only after a sufficient quantity of water has been absorbed.

Water Economy in Plants

You might have experienced that the shade of a tree is more moist than the shade provided by a tiled roof. This is due to the evaporation of large quantities of water from the exposed surfaces of plants. The process is called **transpiration.** If you cover a small potted plant with a bell jar, you will soon notice drops of water deposited on the wall inside the bell jar. These drops represent the water lost by transpiration from the plant. Evaporation of water takes place mainly through the stomata (**stomatal transpiration**), and to a small extent from the cuticle (**cuticular transpiration**).

The amount of water that a plant loses is sometimes greater than its own weight, especially on a dry sunny day. A maize plant is estimated to lose about 231 litres of water during its period of growth (Fig. 44.1). Unless such losses are made good by absorption from the soil and rapid conduction through the stem, shoots and leaves become flaccid and wilted. Often wilting is observed in soft and broad-leaved herbs in the afternoon hours even when the supply of water is adequate in the soil. This happens because the roots are not able to absorb water as rapidly as it is lost from the exposed parts. Towards the evening when the rate of transpiration decreases, the shoots and leaves recover, for then the absorption of water exceeds the rate of water loss. Should the soil not contain enough water, the plant

will not recover at all and will show a **permanent wilting.**

In xerophytic plants the cuticleis generally so thick that cuticular transpiration isnegligible. Besides, whenever there is an excessive loss of water (and therefore a loss of turgidity of the guard cells) the stomata close down, thus cutting down transpiration effectively.

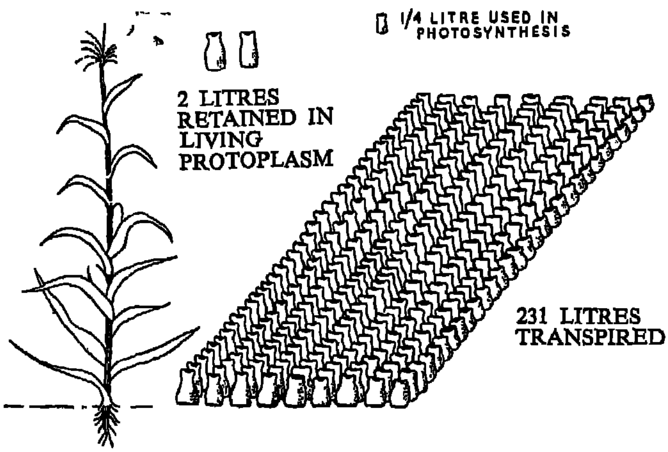

Fig. 44.1. A maize plant releases large quantities of water into the atmosphere by transpiration. It employs only a little of the absorbed water in the synthesis of new materials, and holds a small amount within the living protoplasm. After L.J. Milne and M. Milne, *Plant Life*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1959.

Transpiration does not seem to be of any particular use to the plant. On the other hand, it is a harmful process in which water, a valuable life-sustaining material, is lost. You will recall that the opening of stomata is necessary for the diffusion of carbon dioxide and oxygen for photosynthesis and respiration. Through these same openings the plant cannot help losing water to dry air, and transpiration is a price which it must inevitably pay for the manufacture of food. Some fleshy plants, such as the cacti, accumulate and conserve water in their tissues. The stomata in these plants open at night when it is not so dry, and close during the day—an arrangement which cuts down water loss.

Water Economy in Animals

As you have already read, the water content of our bodies remains more or less constant so that the tissues can function normally. For this, it is essential that we take in at least as much water as we lose. Water is lost mainly through urine, sweat, faeces and breath. Generally, the amount of water lost in urine and faeces is about the same in summer and winter. But in summer a large amount of water is lost in sweat also. In the hot season, therefore, we drink more water to compensate for this loss.

However, you should not think that the function of sweating is to lose water from the body. Sweating is a device to maintain a constant body temperature. Sweat is secreted through certain glands located in the skin. Each of these is a sac-like structure which opens at the surface of the skin and is supplied by an artery, a vein and a nerve. Sweat glands are present only in the mammals. Water and some salts from the blood pass into the cavities of the sweat glands which gradually become filled up and exude this fluid as sweat.

Let us see how the elimination of sweat helps in the regulation of temperature. When you enter a warm place, the temperature receptors located in your skin send the stimulus to a temperature controlling centre in the brain. This sends another set of stimuli to the sweat glands which then contract and give out sweat and thus dissipate the heat from the body.

In a cold environment another set of temperature receptors is stimulated, and they in turn stimulate the temperature centre in the brain. Then stimuli from here pass to the muscles which begin to contract rapidly. So you begin to shiver. Shivering increases the production of heat in the body. The skin also gets wrinkled (and therefore reduced in surface) so that less heat is lost from the body. Thus the mammals maintain a constant temperature of the body whether they are in a cold or a warm place. The birds are the only other group of animals which can maintain a constant body temperature. Birds and mammals are therefore known as warm-blooded animals. Birds do not possess sweat glands, but they too have a temperature controlling centre in the brain.

Among mammals, camels can live for long periods without water. They excrete very thick urine containing only a small volume of water and considerable quantities of urea. But how does the camel manage to lose even this amount of water when it cannot get any for weeks? It has been shown that some of its organs are capable of functioning normally even after losing nearly 30 per cent of their water, whereas our cells can afford to lose only up to 15 per cent of water. The camel is, therefore, better adapted to live under dry conditions than we are. Furthermore, the camel utilizes the water produced when the carbohydrates and fats are broken down during oxidation. Ordinarily the amount of this water, called **metabolic water,** is insignificant. However, in camels, which store and oxidize a lot of fat, it may be considerable. Camels also have the unique capacity to store a lot of water in special folds of skin.

The story of the preservation and loss of water is quite different in aquatic animals. In the freshwater fishes like 'rohu' and 'katla' the concentration of water inside the body is less as compared to that in the river or pond. Water therefore continuously enters into the body by diffusion through gills and through the mouth. The entry of too much of water is dangerous as that would dilute the blood and the cell contents. These fishes continuously give out large volumes of urine, thereby eliminating the excess water which gets into their bodies.

In the blood of marine fishes, however, the total concentration of salts and organic substances is less than the total concentration of salts in sea water. In other words, the concentration of water is greater inside their body, and therefore water continuously escapes by diffusing through gills. If this water loss is not compensated, the body would become dehydrated even when the fish is in a sea of water! So the fish drinks sea water frequently and if this is prevented, it dies in a few hours. Drinking of large amount of water, however, brings in a lot of salts and creates other problems. The intestinal wall and the renal tubules of fishes, therefore, have the special ability to absorb mostly water and eliminate the excess salts through urine. Their gills also have specialized secretory cells for eliminating salts.

In some invertebrates, like the snail and cockroach, loss of water through urine is very small. They excrete solid urine which contains uric acid. In the rainy season, when water is available in plenty, the snail excretes

large volumes of urine containing urea, but in summer it lives under mud and excretes only a small amount of urine containing more uric acid than urea. Vertebrates like lizards and birds also excrete solid urine containing uric acid and not urea. This is very advantageous to them as they live in such habitats where water is not always available. Others like fishes, frogs and mammals can afford to lose water in urine as they usually live in an environment where water is not scarce. Thus you can see that the nature of the urine changes according to the availability of water.

Next, we come to the problem of water loss by way of expiration and faeces. The amount of water lost by these two processes is generally the same in all seasons. This loss is made good by taking in water both by drinking and with food. If we do not take water for a long time, we feel thirsty. Why? It is believed that there is a place in the brain which is sensitive to the concentration of water in the blood which is supplied to it by the arteries. When we do not take water for several hours, the concentration of water in the blood and organs decreases. This blood reaches the thirst centre in the brain and stimulates the desire for drinking water. If you drink salt solution, you will feel thirsty earlier than if you drink ordinary water.

SUMMARY

Water is very important for all plants and animals as it is the medium in which all chemical reactions occur. The total amount of water in plants and animals is 70-75 per cent of the body weight. But the amount of water in different tissues and organs may vary greatly.

All plants and animals have mechanisms to maintain a constant water level. Water is lost from plants mostly by transpiration through the leaves and other soft parts. This loss is made good by taking water from the soil through the roots. In animals water is lost by way of urine, sweat, expiration and faeces. These losses are compensated by drinking water and by the water contained in the food.

In animals an interesting type of adaptation to availability of water is seen in the type of nitrogenous waste matter excreted in the urine. Those with an abundant supply of water excrete ammonia whereas those with a lesser supply of water excrete urea or uric acid.

QUESTIONS

1. Explain the importance of water in living organisms. Do you think there is any other liquid which can replace water?

2. Through what organs does a plant lose water? How will you set up an experiment to show that the amount of water lost is nearly equal to the amount taken up by the plant?

3. What do you understand by 'metabolic water'?

4. What are the ways in which water is lost by mammals? How is this loss made good?

5. Compare a camel and a marine fish with respect to their physiological adjustment for conservation of water.

6. Some animals are capable of changing the form of the nitrogenous waste matter which is excreted in the urine, while others cannot. Explain this with examples.

7. Think of a situation in which the well-known verse: 'Water, water everywhere, not a drop to drink,' may be scientifically true.

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CHAPTER 45

Growth and Development

ALL living things keep on growing as long as they live. Now you may well wonder: "I am growing but my father and grandfather are not growing in height any more." While it is true that the growth in size of any organism comes to an end sooner or later, there are other signs of growth which even your grand father shows, such as the growth of nails and hair.

You will recall that all sexually reproducing organisms arise from a single cell. This cell is the zygote or the fertilized egg. The first phase of growth is initiated by cell division. The young masses of cells, which look quite similar to start with, begin to acquire different shapes and sizes leading to the differentiation of various tissues and organs, and thus the organism enters into the second phase of growth called **development**. Then there comes a period of **senescence** when the rate of growth becomes slower and slower and life ends. It is hardly necessary to emphasize that growth is a highly co-ordinated and integrated phenomenon in which divisions, enlargement and differentiation of cells must proceed in a precise and predetermined sequence.

In animals growth is associated with increase in the number and size of almost all the cells. In most plants, however, in later stages growth becomes localized mainly at the tips of the stem and root and in the layer of cells called cambium. In those parts of the world where the cold is severe, the growing parts undergo seasonal rest in winter and resume activity in the spring. The growth rings in trees, which you have studied earlier, result from such variations in growth.

If you closely observe a young growing root of a seedling you can easily locate three different regions showing the three phases of growth. For this purpose, mark out with Indian ink one millimetre distances from the tip of a young root. If you measure these distances after 24 hours you will notice just a little increase at the tip (mainly due to cell divisions), large increases upwards (due to enlargement of cells), and very little increase higher up in the region of maturation (Fig. 11.9; p. 111).

You could, likewise, measure the size of a young leaf as it grows at successive intervals. The increase is slow in the beginning; later it becomes very rapid but slows down again. Try the same with any other organ of a plant and indeed for the plant as a whole. In every case—in plants or animals—you will find that growth follows an identical pattern. If the growth is plotted against time one gets an S-shaped or **sigmoid curve** as shown in

figure 45.1. However, as distinguished from the rate, the nature of growth and development is specific for each organism. From more or less similar basic materials and nutrients, the organism produces complex constituents like cell walls and proteins that are unique to it. It is like using similar bricks and mortar for constructing houses with entirely different designs.

What is the mechanism by which different parts of the body show a co-ordinated growth? Why does not one of your hands grow longer than the other? Similarly, why do the upper branches in a tree generally not grow more than the lower ones? The mysteries surrounding these questions began to be uncovered only by the discovery of hormones in animals and plants.

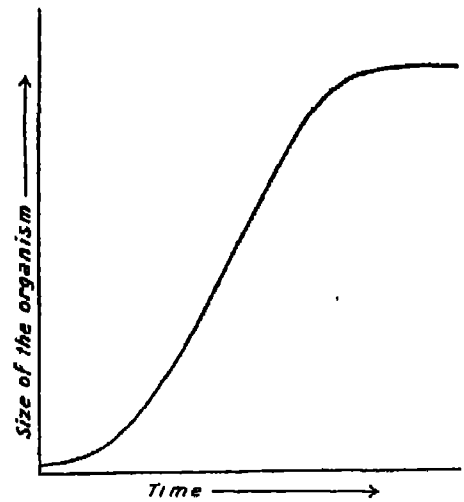

Fig. 45.1. The sigmoid growth curve. This curve is characteristic of single cells, tissues, organs, organisms and populations. Courtesy of the Department of Botany, University of Delhi.

REGULATION OF GROWTH AND DEVELOPMENT IN PLANTS

The Discovery of Growth Regulating Substances in Plants

You probably know about the phenomenon of **phototropism**—the bending of plants towards light—which has doubtless been observed by man since a long time. About a century ago Charles Darwin and his son Francis Darwin became fascinated with this problem. They grew some seedlings of a grass called *Phalaris* in total darkness, and found that if light was shown through a slit from one side, the seedlings bent towards the source of light. The bending occurred at some distance from the tip (Fig. 45.2 A). They became interested in knowing whether the entire seedling or only a part of it had to be illuminated. They divided their seedlings into two lots, and wrapped them individually with pieces of tin foil in such a way that in one lot only the tip of each was covered and in the other only the base. They discovered to their amazement that bending occurred in the second lot but not in the first in which the tips were covered. They further noted that the tips were important not only for bending but also for growth. Thus if the tips were removed, growth ceased (Fig. 45.2 B). But upon their replacement on the cut stumps, growth was resumed.

The conclusions of the experiments by the father and the son could be summarized as follows: (1) The tips controlled in some way the growth of the regions below; in other words there existed 'messengers' in plants

which could influence events in remote regions, and (2) light somehow influenced this message in such a way that the darker side grew more than the illuminated side, resulting in a curvature towards light.

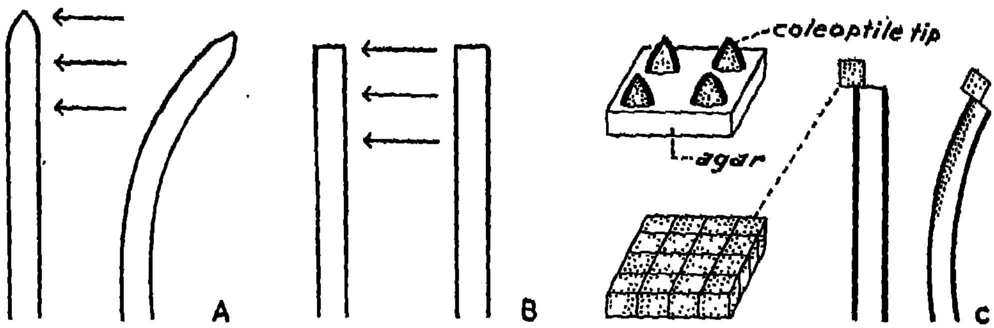

Fig. 45.2. Experiments of Darwin (A and B) and Went (C). Light falling from one side (shown by arrows) upon the tip of a grass coleoptile causes the coleoptile to curve towards the light. If the tip of the coleoptile is excised, no phototropic response is exhibited by the coleoptile. F.W. Went put a large number of tips of oat coleoptile (only four are shown in the figure) on an agar slab. After three hours he divided the slab into small rectangular blocks and placed them asymetrically on the stump of the coleoptile. The coleoptile bent even without light as though the tip were still there. Courtesy of the Department of Botany, University of Delhi.

Later investigators found that the tip transmitted its influence even when a layer of gelatin was placed between it and the stump. Furthermore, bending could be caused even in complete darkness provided the tip was replaced acentrically (the curvature occurred towards the side which was not under the tip). This suggested that the bending of the seedlings was due to an unequal influence of the tip on the two sides of the stump. It was possible that the tip secreted a growth promoting substance which in illuminated seedlings was either destroyed by light or translocated to the shaded side resulting in a higher concentration of growth substance on the darker side. This explanation was of course merely a conjecture; at that time nobody knew whether the tip really produced any growth substance.

It was a truly remarkable achievement when F.W. Went (a Dutch botanist, settled in the USA) in 1928 actually collected the postulated growth substance. He cut off the tips of a large number of oat seedlings and placed them on a jelly-like substance called agar-agar. After about three hours he placed a minute chunk of the agar block on an oat seedling the tip of which had been removed. To his surprise he found that the seedling resumed growth, and responded to light or darkness as though its original tip was there (Fig. 45.2 C). In other words, the agar block acquired what the tip normally has in the intact plant. Obviously, from the agar block something diffused out, and caused an elongation of the side of the coleoptile on which the block was placed, resulting in a curvature.

The growth substance which Went collected in the agar block was chemically identified as **indoleacetic acid.** It is produced in such minute amounts that some 1,000,000 tips of seedlings are required to get just a milligram of it. Luckily, however, chemists today can synthesize similar com-

pounds in the laboratory. These are called **auxins** (from a Greek word which means 'to grow') and are one of the several types of organic substances that are secreted by cells in extremely minute amounts and are transported to other parts or organs of the body where they produce their effects. These substances are also called **plant hormones** or **plant growth substances.** Study figure 45.3 to see how the growth of the various parts of a plant is controlled by many plant hormones.

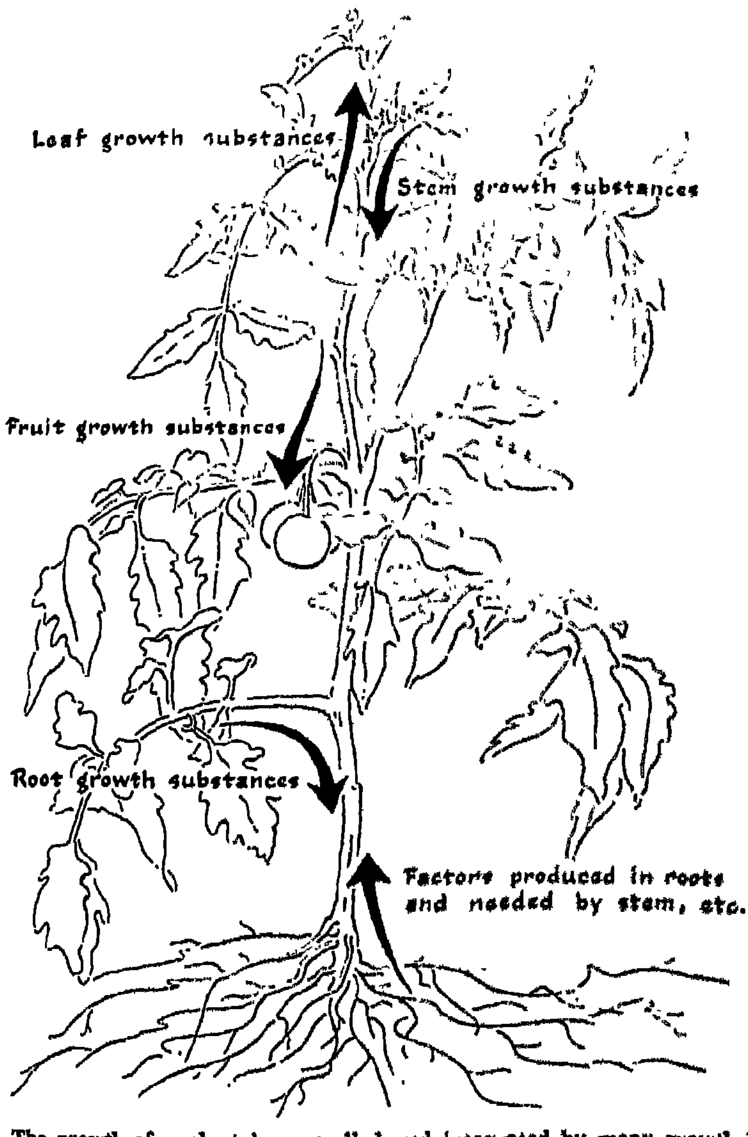

Fig. 45.3. **The growth of a plant is controlled and integrated by many growth hormones, each produced in a particular organ and translocated to other regions.** From J. Bonner and A.W. Galston, *Principles of Plant Physiology*, W.H. Freeman and Company, San Francisco, 1952.

Perhaps no other discovery in this century has so profoundly affected agriculture as the discovery of plant hormones. They control practically every phase of the growth and development of plants. They can have different effects at different concentrations and by judicious use one can bring about effects as diverse as killing a plant or making it grow better. The hormones can thus be employed for inducing flowering in pineapple, for stopping the early fall of fruits in apple, for promoting rooting from stem cuttings, for killing weeds such as water hyacinth, and for inhibiting sprouting in potatoes. They can also be sprayed on grapes, melons and tomatoes to obtain large and seedless fruits even without pollination.

Besides auxin, some other groups of growth substances have also come to light. One group of these is known as **gibberellins** which can make plants unusually tall (Fig. 45.4). Like auxins, gibberellins can also affect plant growth. Figure 45.5 shows how gibberellin treatment has not only increased the size of the cabbage plant but has also induced early flowering.

Effect of Light and Temperature on Growth and Development

With seasons not only temperature, light and moisture conditions change but also the plants and animals around you.

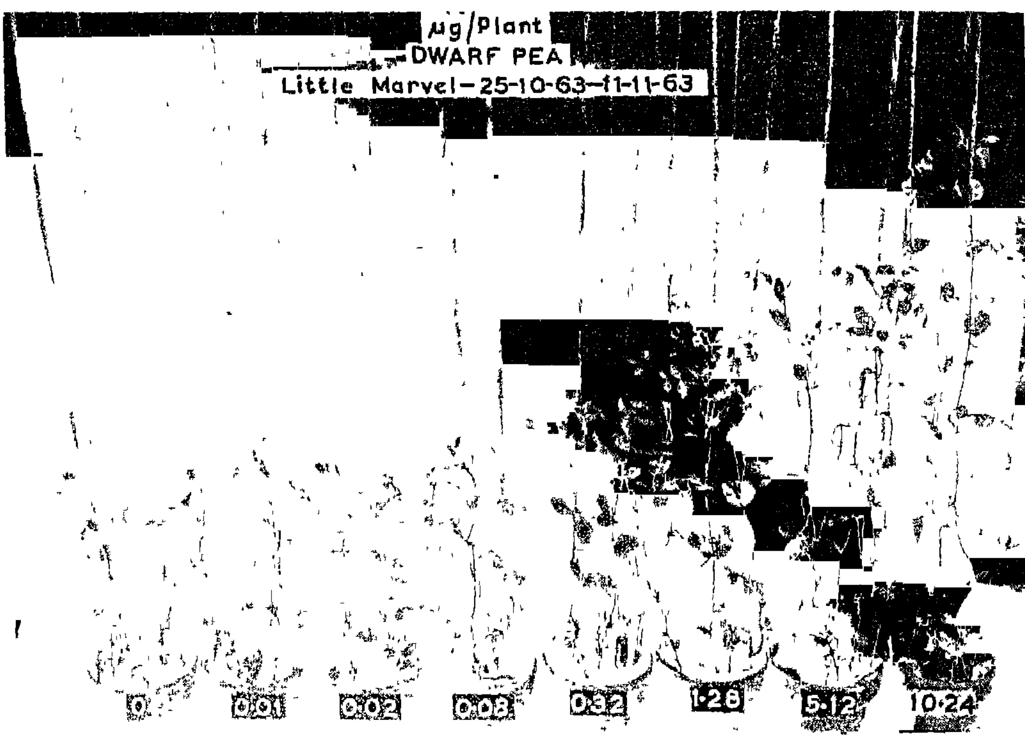

Fig. 45.4. Effect of gibberellin on dwarf peas. Note that the treated dwarf plants have become taller. Within limits, the greater the amount of gibberellin applied (concentrations in micrograms are written on the pots) the taller the plants become. Courtesy of Ramesh Maheshwari, Department of Plant Pathology, University of Wisconsin, Madison, USA.

Fig. 45.5. Cabbage plant treated with gibberellin. This has resulted in its enormous elongation and early flowering. Courtesy of S. H. Wittwer, Michigan State University, East Lansing, USA.

In many plants the change-over from **vegetative phase** to **reproductive phase** takes place in response to the **photoperiod,** i.e. the length of the day. As you know, day-length changes according to location and season. In the Northern Hemisphere, in which our country is situated, the days are longer during May, June and July, and shorter during November, December and January. The reverse is the case in Australia or New Zealand which are in the Southern Hemisphere. They have summer when we have winter in our country, and their winter arrives when we have summer here.

Some species of plants flower only when the day-length is shorter than a certain critical period. These are called **short-day plants.** Many of our garden plants such as cosmos, chrysanthemum and petunia, are short-day plants, and they normally flower in winter. Others, like *Hyoscyamus* and *Hibiscus*, are **long-day plants.** There are of course a number of plants which do not respond in this manner to day-length, and flower all the year round. These are called **day-neutral plants.** Maize, tomato and chilli are examples of this kind. This information is very useful from a practical point of view. You can, for instance, delay the flowering of a short-day plant by giving it artificial light after the sun has set. The same result can be achieved with a long-day plant by placing it in the dark before sunset. It is also possible to induce early flowering and thus obtain off-season flowers and fruits. Control of flowering is of special interest to plant breeders. Often in the past they have wished to hybridize plants to obtain better varieties, but were disappointed on account of the different times of flowering of the two parents. However, now they have the knowledge to overcome these difficulties.

There is evidence that in both short-and long-day plants the stimulus of light and darkness is perceived by the leaves. Thus, if you defoliate a short-day plant and then provide it the appropriate hours of darkness, nothing will happen. But if you retain a single leaf or even a part of it, the plant will flower (Fig. 45.6). Moreover, when a short-day plant is subjected to short-day conditions, not only does it flower itself, but it can also transmit the flowering capacity to another plant (which has not

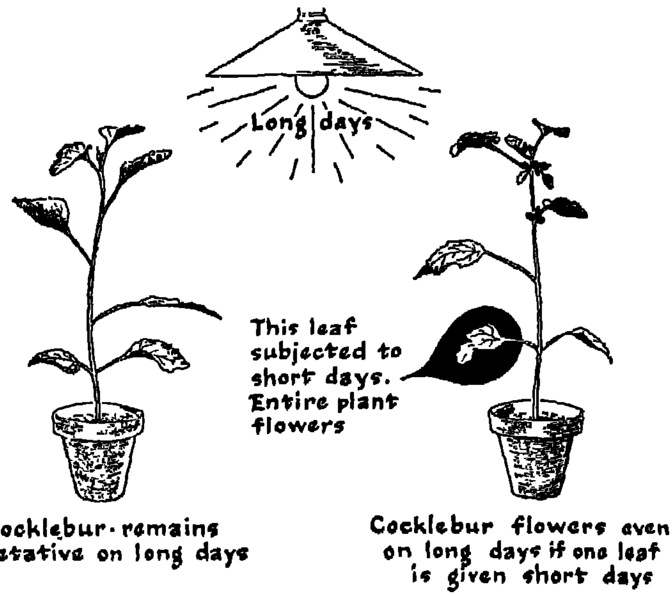

Fig. 45.6. In many plants, such as cocklebur, short-day treatment of a single leaf results in flowering. From J. Bonner and A.W. Galston, *Principles of Plant Physiology*, W.H. Freeman and Company, San Francisco, 1952.

been subjected to short-day conditions) through a graft union (Fig. 45.7). However, nobody knows what exactly happens in a leaf, and how flowers begin to be formed. Whether plants have an unknown flowering hormone, only future can tell.

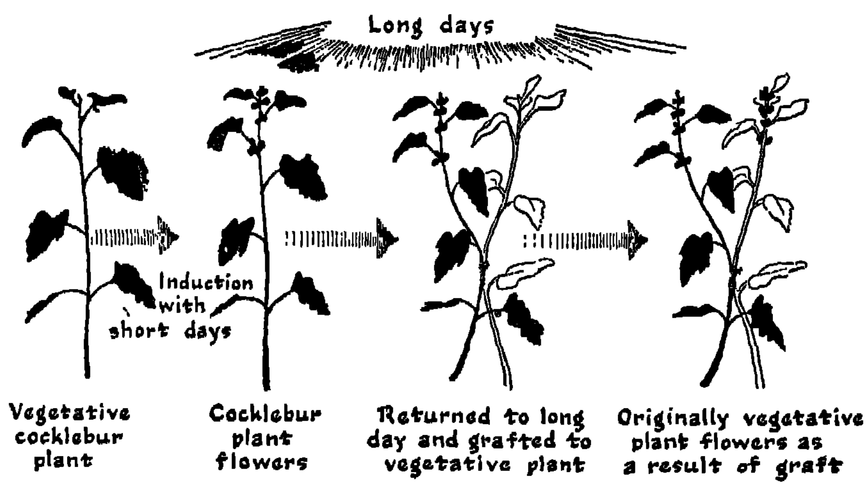

Fig. 45.7. The flowering stimulus may be transmitted from plant to plant across a graft union. From J. Bonner, and A.W. Galston, *Principles of Plant Physiology*, W.H. Freeman and Company, San Francisco, 1952.

REGULATION OF GROWTH AND DEVELOPMENT IN ANIMALS

In Section III we have already discussed the role of hormones in animal development. Chemically, the animal hormones are quite different from plant hormones, though their general properties are the same. There are probably not more than a few gammas (1 gamma=0.000001 gm) of thyroxine, adrenaline or the pituitary hormones in the human body and yet they have a profound influence on the growth and development of the body (Fig. 45.8).

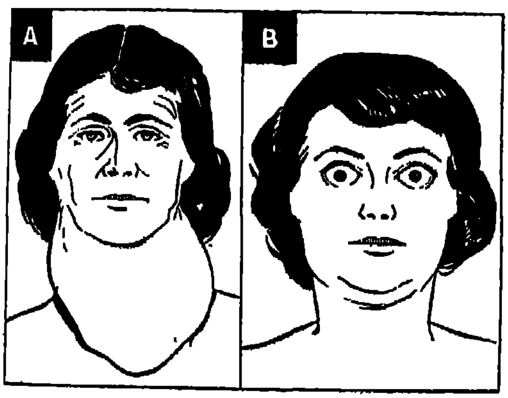

Fig. 45.8. Effects of thyroid gland malfunction. A. Goiter. B. Exophthalmia. From G.G. Simpson, C.S. Pittendrigh and L.H. Tiffany, *Life—An Introduction to Biology*, Harcourt, Brace & Company, New York, 1957.

Role of Tissue Interaction in Differentiation

To understand the interaction of tissues, let us recall the development of the fertilized egg of frog which differentiates into an embryo with an ectoderm, mesoderm and endoderm. It has been observed that the ectoderm gives rise to the brain and the spinal cord. J. Holtfreter, an embryologist, excised a piece of ectoderm from an early embryo and put it in a dish of salt solution. The cells of the ectoderm lived and remained healthy, but did not form the brain or the spinal cord. However, when he kept a piece of excised mesoderm adpressed to the ectoderm in the same dish, he found that this caused the development of nervous tissue from the ectoderm. This was indeed a very exciting observation. It showed that perhaps there is some type of **interaction** between the two layers, or that some chemicals from the mesoderm stimulate the ectoderm to develop into the nervous system. It is not yet known how this interaction occurs, but it is believed that some hormones are responsible for the differentiation of cells into organs.

Regeneration

Regeneration is of limited occurrence in the insects and vertebrates. You have experienced that if a piece of skin or tissue is lost from a man's body, the wound heals and after some days the skin is completely filled up. However, if one loses a finger, the loss is permanent.

The lower animals like *Hydra*, *Planaria* and starfish show a more successful regeneration of lost parts than higher animals. If *Hydra* is cut into pieces, each piece grows into a separate and complete animal. If *Planaria*, a free-living flatworm, is cut into two or three pieces, each piece will form a new animal (Fig. 45.9).

Uncontrolled Growth and Cancer

When the cells divide and differentiate normally, new organs are formed. Sometimes, however, regulatory control is lost. Cells divide wildly and wander around.

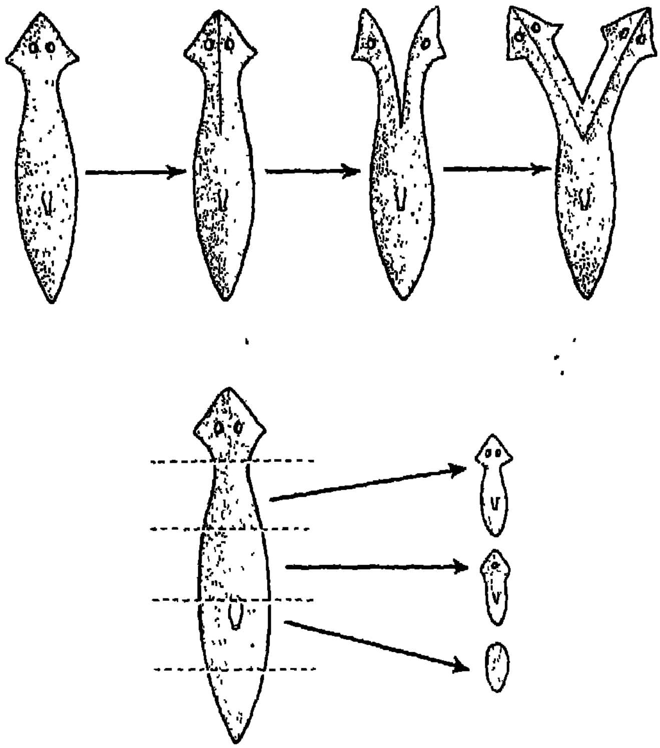

Fig. 45.9. Regeneration in *Planaria*. This animal shows a tremendous capacity to regenerate the entire organism from cut portions of its body. Courtesy of the Department of Botany, University of Delhi.

They may become lodged in awkward places and continue to multiply without much differentiation. This results in a dreaded disease called cancer which takes a toll of many people every year. Some types of cancer are believed to be caused by viruses. If cancerous tissue is detected at an early stage, it can be treated by X-rays which kill the wild cells.

SENESCENCE

After a plant or animal attains a certain age, it becomes old and ultimately dies. Many scientists are trying to find out what physiological changes bring about ageing or senescence in man, and why an old man is not as capable of doing all types of work as he was in his youth. If the mechanism underlying these changes can be discovered, it may be possible to arrest old age.

SUMMARY

Growth is one of the chief attributes of life, and involves three basic processes: cell division, cell enlargement, and cell differentiation. These processes are controlled by a group of organic substances called hormones. Usually growth follows a definite pattern. It is slow in the beginning, then it suddenly becomes rapid and eventually slows down.

In plants there are hormones like auxins and gibberellins which are responsible for cell enlargement. The effects of temperature and light on phenomena like flowering and seed germination are also probably mediated by hormones. In animals hormones are produced by thyroids, pituitary and other glands which control the various processes like growth, maturity, concentration of blood sugar, nervous action and senescence.

Cells sometimes become malignant and divide wildly giving rise to cancerous tissue. This happens in both plants and animals. No one yet knows what makes cells go wild, or what makes them differentiate into organized tissues and organs. Scientists are, however, trying to solve these questions, through the use of tissue culture technique, and probably a lot will be learnt during the the next 20 years.

QUESTIONS

1. Distinguish between growth and regeneration.
2. What are hormones? Why are they important?
3. Can you alter the rate of growth in an organism? If so, how?
4. What do you understand by differentiation?
5. Why do plants bend towards light?
6. What is regeneration? Does a human being show this phenomenon?
7. Seedlings grown in dark are taller than those grown in light. Does it not prove that plant growth occurs more in darkness than in light?
8. Why is a cancerous growth of tissue dangerous for the life of an organism?

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CHAPTER 46

Responsiveness and Co-ordination

SUPPOSE you were asked how you spent your summer vacation, you would probably reply that you enjoyed yourself very much. Now, can you analyze how exactly you did it? Biologically speaking, this was possible because you possess several organs which enable you to see, to hear, to smell, to taste, to feel and to appreciate beautiful things. These organs are the eyes, nose, tongue and skin. All of these work in co-operation or **co-ordination** under the guidance of a master organ—the brain. When you look at an object, perhaps you think that your eyes are enabling you to see the object, and when you hear a sound you feel that your ears are recording it. However, this is only partly true. To a large extent your reactions toward the environment are due to the work of your nervous system.

The reaction of an organism or its organs to a particular type of stimulus is called **response.** A **stimulus** is a change in any factor of the medium or environment that surrounds the organism.

A responsiveness to stimuli occurs in all organisms, but the degree and kind of response vary a great deal. An *Amoeba* promptly withdraws its pseudopods and stops its activities if the temperature and chemical factors in the surrounding water are unfavourably changed. However, the most spontaneous response is seen in the vertebrates which have a highly organized and well-developed nervous system.

Structure of the Nervous System

The nervous system consists of the brain, the spinal cord, and the nerves. The brain and the spinal cord form the central nervous system (CNS) and the nerves form the peripheral nervous system. The CNS receives information through the sensory nerves from various sense organs such as the eyes, nose, ears, tongue, skin and the receptors located in various parts of the body. Then the CNS sends appropriate messages to the muscles or glands through the motor nerves. The brain, spinal cord and nerves are all made up of nerve cells called neurons (*see* Fig. 6.25). The body of a nerve cell is irregular and somewhat star-shaped. It bears numerous slender fibres or dendrites and a long fibre or axon. The nucleus and most of the cytoplasm of a nerve cell are contained in the main body of the cell. The dendrites of one neuron lie very close to those of another neuron, and the junction is called a **synapse.** The axon varies with the size of the animal and the distance of the organs from the CNS. The longest axons

in the human body are those extending between the toe and the brain. In whale the axon may be several metres long. A nerve consists of a bundle of axons enclosed in a sheath, and can be compared to a telephone cable. At the distal end of the nerve (that is, where it ends in a sense organ or a muscle) the sheath is absent and the nerve fibres (axons) are loose and much branched. When a sense organ is stimulated, the fibres at the free end of the nerve ramifying in it pick up the stimulus which may now be called a nerve impulse. The impulse jumps on to the dendrites of another neuron which then sends the impulse along its axon. Thus, through the synapse the nerve stimulus passes from one nerve cell to another (Fig. 46.1).

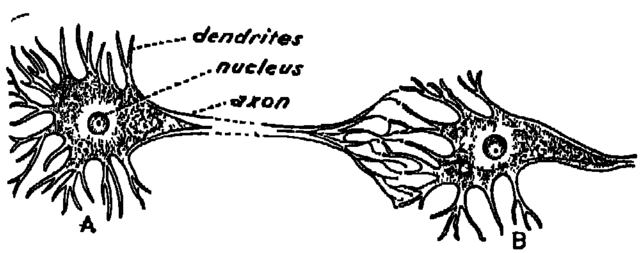

Fig. 46.1. An impulse can pass from A to B across a synapse. Cell A is shortened (*see* the dotted lines). Cell B is incomplete. Copy this diagram, complete the cell B and show how the impulse would get into another cell C, beyond B. After E. Kroeber, W.H. Wolff and R.L. Weaver, *Biology*, D.C. Heath and Company, Boston, 1960.

Transmission of Nerve Impulse

The conduction of the nerve impulse can be compared to the transmission of messages through a telephone cable. The telephone wires carry a message to the telephone exchange and from there the message is transmitted to different places through another set of cables. Similarly, the nerves carry an impulse first to the brain or spinal cord. These analyse the message, and produce and transmit an appropriate response through another set of nerves to the muscles or glands. The synapses permit the flow of nerve impulses only in one direction. However, in an isolated nerve an impulse generated in its middle portion can travel in either direction.

The impulses travel back and forth along the respective nerves at a very fast rate though not as fast as an electric current passing through a wire. In animals like the elephant and whale which have very long axons the speed of conduction of a message is about 100 metres per second. In smaller animals, having shorter nerves, the speed is less (*see* Table below). In general, the speed is faster in the warm-blooded animals than in the cold-blooded ones. Moreover, longer and thicker nerves conduct the stimulus much faster than the shorter and thinner nerves do.

SPEED OF CONDUCTION OF IMPULSES IN THE NERVES OF ANIMALS

Mammals	50-120 metres/sec.
Fish	10-35 ,,
Frog	20-30 ,,
Snake	10-35 ,,
Earthworm	
(giant fibre)	10-30 ,,
(narrow fibre)	0.5 ,,
Octopus	5-8 ,,
Snail	0.4 ,,

Receptor Organs

The receptor or sense organs are the sentinels of the body placed at appropriate places. The eyes, ears, tongue, nose and skin are located on or near the surface of the animal. So they receive stimuli from outside. Besides, there are many built-in receptors which inform the brain about

the internal environment of the body and produce sensations of muscular tension, hunger, thirst, nausea, etc.

Eye (photoreceptor organ). The eye is a photoreceptor organ as it is stimulated by light. It helps us to detect or see the lighted objects. You have learnt in Chapter 28 that the eye has a pigmented layer of cells called the retina. This is made up of two types of cells, the rods and cones, which are connected to nerve fibres.

The rods are sensitive to dim light and contain a brown pigment called **rhodopsin** which is formed from vitamin A. The rods enable us to see shades of grey and white. They also help us to see in dim light and in dark. If the food does not contain enough of vitamin A, one is unable to see anything in dim light. This defect is called night-blindness, and results from insufficient rhodopsin in the rods. You might have experienced that when you move from a brightly lighted place to a poorly lighted one, you cannot see things for a few seconds. This happens because the rhodopsin gets bleached by strong light and until more of it is produced, one cannot see properly.

The cones enable us to see the various colours. There are three types of cones, each containing a different pigment. These enable us to see the three primary colours—red, green and blue. The absence of any one type of cones results in a failure to see the corresponding colour. Those who have no cone in their retina cannot see any colour. To them the whole world looks only black, dull white or grey as if they were seeing things in a moonlit night (the light from the moon is not bright enough to stimulate the cones). About eight per cent of the men and one per cent of the women in the world are colour-blind. Some of them cannot distinguish between red and green, others between yellow and blue.

The rays of light falling on the retinal cells generate impulses which are carried by the optic nerve to the brain. The impulses are analyzed in the visual area of the brain. It is only then that we know what we have seen. If the optic nerve is cut we cannot see anything, since the impulse does not reach the brain any longer.

When we look at an object, its image is formed on the retina. This image is inverted as in a camera. However, after the brain has analyzed it, we get the upright impression of the object. The image is focussed by the lens on the yellow spot. In a camera the image is focussed by moving the lens forwards or backwards. In the eye the lens does not change its position for focussing; it changes its curvature. For focussing distant objects, it becomes more flattened; for nearby objects, more convex.

If you look at your friend's eye, you will see a black circular area at the centre of the iris which is the coloured part of the eye. The black area is called the pupil which is comparable to the aperture of the camera. It becomes wider in dim light and thus lets in more light. In bright light, it becomes smaller and allows less light to enter.

Ear (auditory and balancing organ): The structural details of the ear were described in Section III. When sound waves strike the ear drum, the vibrations ultimately reach the spiral sac or cochlea through a system of bones. The fluid in the cochlea is set in motion and auditory cells are stimulated. The movement of the fluid depends on the frequency of the sound waves. The stimulus is carried to the brain through the auditory nerve. Just as vibration of the wire of a violin at different places produces sounds of different pitch, here too the

auditory cells—in different parts of the membrane of the cochlea—are sensitive to different pitches of sound. The cells at the base of the cochlea are stimulated by sounds of high frequency while those in the upper part are stimulated by sounds of low frequency. This is how you distinguish the barking of a dog from the sweet note of a violin.

Tongue. We have said before (in Chapter 28) that chemicals stimulate large ciliated cells in the taste buds. In each taste bud there is a tiny nerve branch which generates a nerve impulse. The latter is carried to the taste area of the brain. Different regions of the tongue are sensitive to different tastes. There are certain chemicals, like phenylthiourea, which taste bitter to some people but are tasteless to others. The ability or inability to taste certain substances is a hereditary character. If phenylthiourea tastes bitter to you, it will also taste so to one of your parents or to both.

The nerve endings on the tongue and those in nose are closely connected to each other. Therefore, though you may think that you can tell a spice by tasting it, in reality you do so by smell rather than taste.

Nose. This organ is also a chemoreceptor since it has cells which are sensitive to chemicals. A chemical present in the air first dissolves in the fluid surrounding the sensory cells and then stimulates them. Fundamentally, therefore, the nose and the tongue are similar in their sensory capacity.

Cutaneous Receptors. Several types of receptors are located in the skin. Thus there are temperature receptors, pain receptors and touch receptors. All these are supplied with nerves which are connected with specific areas of the brain.

The external receptors give information to the animal about its environment by seeing, smelling, tasting, touching or hearing, so that the animal is able to adjust and co-ordinate its activities according to the environment. For example, when we see a tiger we run for protection. If the temperature of a place is too high, we move to a cooler place. The responses to all these stimuli are voluntary, i.e. they are carried out with the knowledge of the animal. These responses occur rapidly; the information is received through one set of nerves, and the brain sends the messages along another set of nerves. The muscles are the responding organs; their activities are regulated by the nerves. However, in many instances, instead of the muscles the glands are the responding organs. For example, when food enters the mouth, the taste receptors stimulate the salivary glands to secrete the digestive enzymes.

Besides the external receptors, the internal organs also have sensory cells which facilitate the normal functioning of the body. The muscles and tendons have strain receptors which are supplied with sensory nerves. If these organs are stretched beyond a certain degree, the receptors are stimulated. The stimulus is carried by a sensory nerve to the spinal cord which sends a corresponding stimulus through a motor nerve to the muscle to stop further stretching. The wall of the lungs has sensory cells which control the degree of expansion of the lungs. Likewise, the diaphragm, the intestinal wall and other organs have receptor cells for the regulation of their activities. In contrast to the external receptors, the stimuli from the internal receptors do not enter the brain but enter the spinal cord. Thus most of the physiological adjustments of the internal organs occur by reflex action through the spinal cord and hence are involuntary.

Reflex Action

If you suddenly step on a nail, you feel a pinch and withdraw your leg instantaneously. How does this come about? In this reaction, the pinching stimulates thousands of pain receptors in the skin which sound the alarm. Messages flash along the nerve to the spinal cord. The spinal cord, in turn, stimulates the nerve supplying the muscle which then contracts. All this occurs in a fraction of a second. When the brain is intact, a nerve fibre from the spinal cord carries the stimulus to the pain centre of the brain (Fig. 46.2). It is only then that you feel the pain. Before this you have already withdrawn your leg, for here the nervous response is involuntary and it occurs before the animal is aware of the stimulus. This is called **reflex action.** Similarly, if you put your hand on a hot stove you immediately pull it back. Have you ever noted this happen even before you feel the pain? A study of the reflex action of frog can be a very instructive experience. If you prick the limb of a frog it shows the same reaction. Now destroy the brain of the frog and prick its foot. It still shows the same reaction (Fig. 25. 26; p. 257). This shows that the brain does not have to know everything that goes on in the body. Many of the functions go on inside the body without the knowledge of the brain.

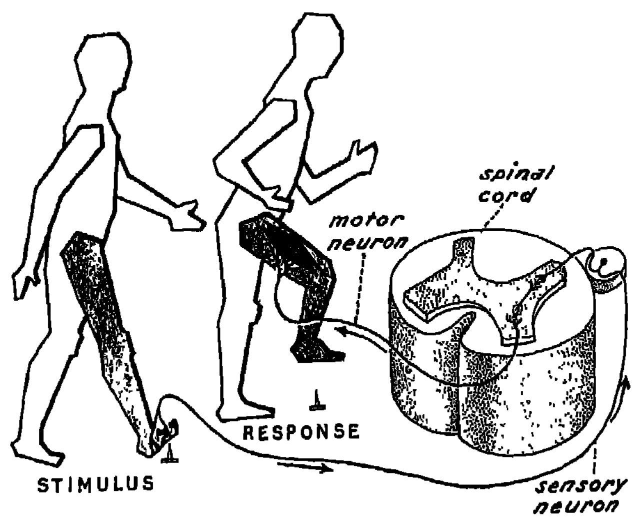

Fig. 46.2. **If you step on a nail, the prick starts a nerve impulse which is carried to the spinal cord, and down it comes back to the leg muscles that make you withdraw your leg instantaneously.** Modified from C.J. Lauby, J.C. Silvan and G.M.A. Mork, *Biology*, American Book Company, New York, 1958.

Controlling and Conditioning the Reflex

By practice you can voluntarily stop a reflex action. Thus, when your hand touches a hot object, you pull out your hand immediately. However, with a strong will power you can keep your hold of the hot object even when your hand starts burning. Similarly several other kinds of reflexes may also be controlled.

When you see some tasty food, saliva is secreted in your mouth. So the normal stimulus for salivation is tasty food. However, Ivan Pavlov, a Russian Physiologist, observed that by appropriate manipulation a salivation response can also be produced by other stimuli which never before produced salivation. Such a change in the reflex response is called **conditioning.** To demonstrate this he designed a simple experiment illustrated in figure 46.3. He took a dog and brought food before it. The animal started salivating. When he rang a bell before the dog, it did not salivate. Thus he noted that the ringing of the bell is not the stimulus for salivation response. Then he

rang the bell and immediately afterwards showed the food. The dog salivated, certainly due to the sight of the food. Pavlov continued doing this several times and every time the dog salivated. Then he rang the bell but did not show the food. To his astonishment he found that even then the dog salivated (Fig. 46.3). He explained this by saying that the dog had been conditioned to respond to a new reflex action. The new action is different from that which

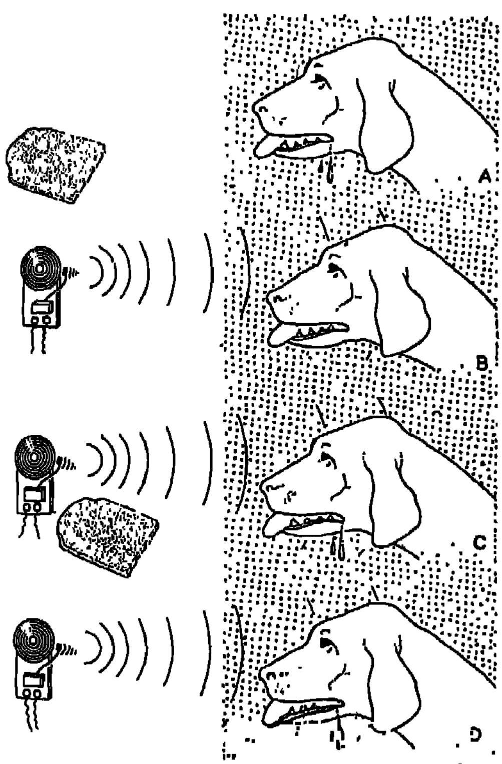

Fig. 46.3. Establishment of a conditioned reflex. The sight of food causes salivation (A) whereas the sound of bell does not stimulate salivation (B). When the sound and food are simultaneously present, salivation is evoked (C). When a reflex becomes conditioned, the sound alone can evoke salivation (D).

occurs when the food is shown. Other reflexes can also be conditioned. With some effort you may learn to play on a harmonium at the same time while you are chatting with your friend. This is an **automatic reflex.**

Autonomic Nervous System

In addition to the central nervous system, animals possess another nervous system called autonomic nervous system. This is closely connected with the central nervous system, and is equally important. However, this acts on glands and organs which are involuntary. Hence we have no control over this nervous system. It causes the contraction of muscles of stomach or makes the heart-beat faster or slower. It also controls all our emotions like anger, fear, joy, etc.

RESPONSIVENESS IN PLANTS

The plants that you see around are rooted to the ground and are immobile. On first sight you may gain the impression that they are unlike animals or that their responsiveness is very limited. However, among plants too there are many motile forms such as *Chlamydomonas* and *Volvox*. The ciliate zoospores of algae and the antherozoids of bryophytes and pteridophytes are also motile. They swim in the water and respond visibly to sudden changes in temperature, light and contact with other substances. Therefore, there is no doubt that fundamentally animal and plant cells have similar properties. In the examples mentioned above the entire plant or the entire colony

responds, and the response is generally directional. The movement of the cilia is co-ordinated by conduction of the stimulus through a fine network of the peripheral protoplasm. However, the exact mechanism of the response is not yet understood.

Other responses to stimuli in plants are more localized. For instance, if you touch one of the leaflets of *Mimosa pudica*, all the other leaflets droop down, and as the stimulus travels (or is conducted) down the rachis the entire leaf folds. The plant recovers from this shock after some time. A similar response is shown by the telegraph plant (*Desmodium gyrans*). A majority of the plants belonging to the pea family show a drooping movement of the leaves in the evening. The mechanism of these leaf movements is not understood; perhaps it involves the movement of water from the parenchymatous cells into the intercellular spaces of the petiole.

The curvature movements observed in response to some stimuli are known as **tropisms.** Thus shoot apices show the phenomenon of **positive phototropism**, i.e. bending towards light. The root, on the other hand, shows **negative phototropism** i.e. it responds by bending in the opposite direction. Bending in response to gravity is called **geotropism.** The roots are **positively geotropic;** the shoots, **negatively geotropic.**

However, plants do not possess any nervous or muscular tissues like animals, nor are there any plant cells that even remotely approach the animal cells in their capacity for conduction of stimuli and for contraction. In this sense, therefore, the co-ordination of various functions is better developed in animals than in plants.

SUMMARY

The control and co-ordination of functions among the various organs occur by specific hormones in plants, and by both nerves and hormones in animals. Co-ordination by nerves is much faster than by hormones. The passage of stimulus in a nerve is an electrical process. Nervous co-ordination requires receptor organs which can be stimulated by specific stimuli. Such organs may be external, e.g. the eyes, the ears, the nose and the tongue; or internal. These organs send the stimulus along a sensory nerve to the central nervous system. The central nervous system then sends the command through a motor nerve to the effector organs which may be muscles or glands. Several activities in the body are controlled by reflex action.

A hormonal co-ordination occurs in animals by specific secretions which are produced in specific endocrine glands. They

generally control various metabolic activities and growth processes. The main glands for such functions are the pituitary, thyroid, parathyroids, the Islets of Langerhans, and the adrenals.

As in animals, hormones are produced also in plants, and control several phenomena, such as movement of plants in response to light and gravity, flowering, and seed germination.

QUESTIONS

1. Can insects distinguish colours ? How will you design an experiment to get the answer?
2. Why is conduction in a nerve called an electrical phenomenon?
3. What is a reflex action? Give five examples of reflex action in your body.
4. Of all the endocrine glands you know, which one has the maximum controlling effects on other endocrine glands? How are these controlling functions carried out?
5. How did Pavlov bring about conditioned response in the dog? What change took place in the dog's brain as a result of conditioning?
6. What is the difference between a reflex response and a conditioned response?
7. Explain the following types of behaviour:
   (a) A child may start crying on seeing its mother putting on shoes.
   (b) Salivation starts in the mouth of some students on hearing a school-bell towards mid-day.
   (c) When a small insect alights on the eye, the eyelids close even before we become aware of the approaching insect.
8. The response of plants to stimuli is generally very slow. Why?
9. How will it affect an organism if the vein coming from one of the ductless glands is severed?
10. What is night-blindness? Name the pigment that enables us to see in dim light.
11. When the bright lights of a motor car shine on a cyclist, he fails to see the coming car rather than seeing it more distinctly. Why?
12. Why is it not advisable to remove wax from the ears with a matchstick, a hair pin or a sharpened pencil?
13. In this chapter we compared the nervous system with the telephone system. List the aspects in which the two are similar and in which they differ from each other.
14. Compare the working of human eye with that of a camera, bringing out resemblances as well as differences between the two.

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SECTION 5

Self-Perpetuation or Reproduction

CHAPTER 47

Reproduction in Plants

IN Chapter 3 we made a general statement that all living organisms have the unique property of producing more individuals of their own kind. Each organism lives for a particular length of time, that is, it has a more or less fixed span of life. During its life, or at any rate shortly before its death, the organism tends to leave one or more young ones which in turn repeat the process. You would have found these facts well substantiated all through your study of the different kinds of plants in Section II. Every kind of plant was shown to possess one or more methods of reproduction. In this chapter, therefore, we shall not concern ourselves again with the details of those methods. We shall rather try now to have a general picture of the various patterns of reproduction in plants, using the information of Section II as the background.

It is generally agreed that the earliest forms of plants were all unicellular. Gradually some of these became multicellular. With the multicellular habit came the wide diversity of forms and specialization of structure as we see today. Along with these changes in form, Nature seems to have experimented in devising suitable methods of reproduction. Consequently, today we find all sorts of variations suited to the particular conditions of life and complexity of structure.

Vegetative Reproduction

The simplest method of perpetuation is **vegetative reproduction** in which any part of the organism, performing the ordinary functions of life, becomes reproductive. In unicellular plants such as bacteria and some algae, the single cell performs all the functions of life. In these, reproduction would simply mean a division (fission) of the parent cell. In bacteria each cell divides into only two daughter cells (binary fission), whereas in many algae the protoplasm of the parent cell divides into more than two parts (multiple fission) each of which later grows into a new organism. In these cases the parent cells change into the offspring. You may even say that the unicellular plants are immortal since their protoplasm becomes evenly distributed into the offspring. In some unicellular plants such as the yeast, the parent cell keeps its identity and produces a daughter cell which is conspicuously smaller. The newly formed cell (the progeny) gradually attains the normal size and repeats the process. This type of fission is termed budding.

A division of the parent into two or more offspring is no doubt a very simple, easy, and quick method of multiplication, and is indeed of universal occurrence in unicellular plants. In multicellular plants, too, the entire individual may just break up into two or more parts each of which then becomes a new plant. This process is called **fragmentation.** Thus, the basal part of a thallus of *Riccia* may die out to the point of its forking, and the two free branches continue growth as independent plants. A filament of *Spirogyra* may also get fragmented by the death of intercalary cells or by accidental breaking into two or more pieces, each piece then growing into a bigger filament.

The process of vegetative reproduction in higher plants (ferns and seed plants) is only slightly different. Here, any part of the plant—stem, root or leaf—is capable of growing into a new plant, in addition to performing its usual functions. Perhaps the most striking example of such reproductive capacity is seen in the leaves of *Kalanchoe.* Like most other leaves these too carry on photosynthesis—their usual function—but in addition they have the capacity to produce one or more plants from the notches in their margins. Thus, if you place a leaf of *Kalanchoe* on damp soil, you can see small buds coming up in the notches in a couple of days. These buds would later form new plants, complete with roots, leaves and stem (Fig. 47.1). More often the capacity for vegetative reproduction resides in roots (sweet potato, asparagus and dahlia) or stems (ginger, turmeric, banana, potato, onion, sugarcane and canna). In all these instances the plant parts are said to possess the power of **regeneration,** which means that a part of the plant can either replace its lost portion or bring forth a new adult plant. The capacity for regeneration is quite common in most higher plants and has been put to great use by mankind since times immemorial. Thus, rose, coleus, pothos and bougainvillaea are generally propagated by placing their stem cuttings in moist soil. The cuttings soon strike roots and grow into new plants. This procedure considerably reduces the time required to obtain a mature plant. Moreover, since the process involves simple cell division, the qualities of the parent plant are faithfully reproduced in the offspring. Some very useful plants, such as the banana and certain varieties of oranges are sterile, that is, they do not produce any seeds. Propagation by cuttings is the only method of obtaining more of these plants.

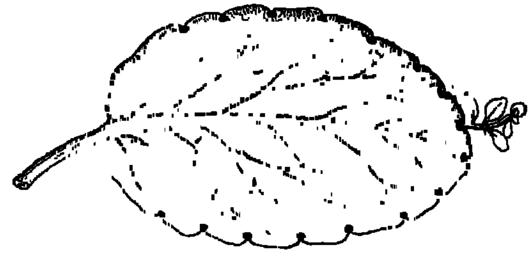

Fig. 47.1. Vegetative propagation from a leaf of *Kalanchoe*. Each of the notches along the margin of the leaf has the potentiality to form a new plant. Courtesy of the Department of Botany, University of Delhi.

Horticulturists have evolved several other methods to produce new plants in a short time. One of these is **layering.** In this, one or more branches of a tree are bent close to the ground and covered with moist soil. In a few weeks the covered portions strike roots and produce plantlets which can be separated from the parent tree as new individuals (Fig. 47.2).

Grafting is another method in which man has remarkably exploited the regenera-

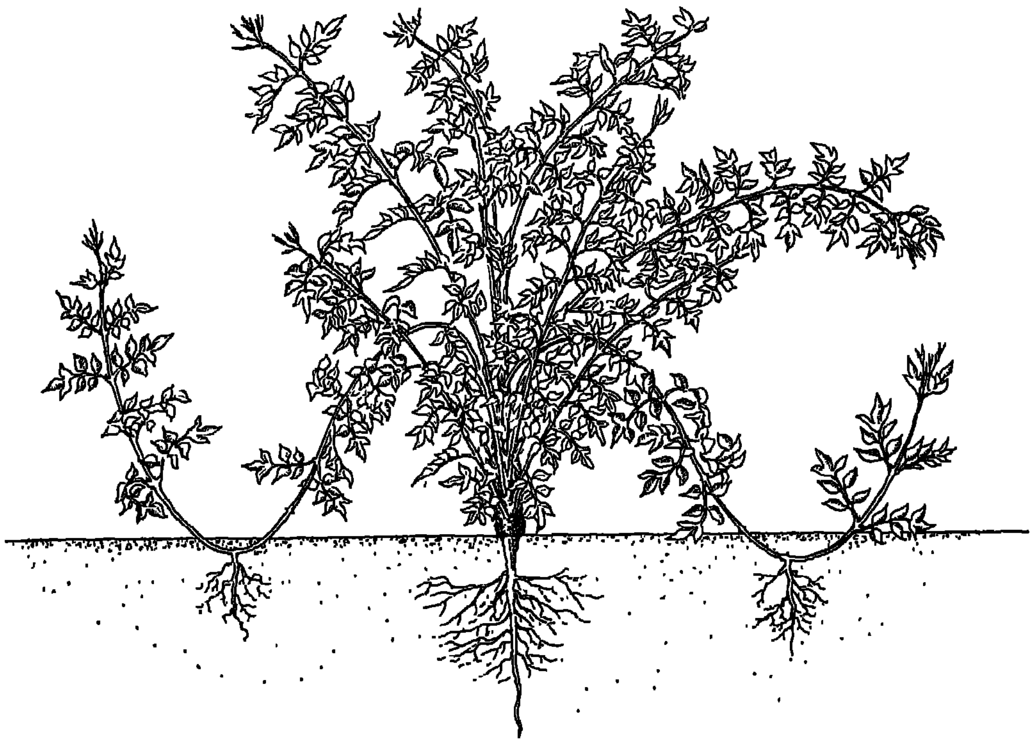

Fig. 47.2. Layering, a common method of propagating ornamental plants. Two branches of jasmine are seen striking roots in the soil. The rooted branches later develop into new plants. Courtesy of the Department of Botany, University of Delhi.

tive capacity of higher plants. It is extensively used for growing roses and mangoes. It is a common experience that a mango tree grown from a good seed will not always bear fruit of the same quality as the parent tree. Other cultivated fruit trees also show such variations. Under such conditions one may resort to grafting, i.e., making a twig or bud of one plant grow on the trunk and root system of another. For example, in mango a branch is cut off from a tree of the cherished variety. This cutting is termed the **scion.** Next a young sapling of mango grown from a seed is selected and most of the shoot part cut away. The rooted stump, usually half a metre or so in height is called the **stock.** The graft is made by fixing the scion on

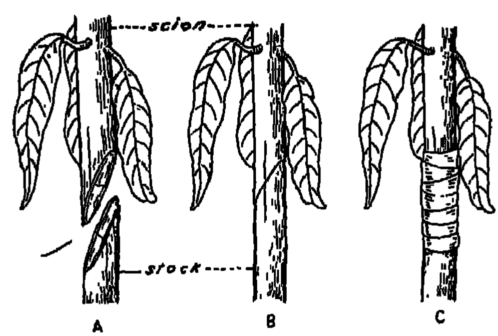

Fig. 47.3. Grafting in mango. The lower end of the scion and the upper end of the stock are cut obliquely (A) and are brought together (B). A tape is then tied round the graft (C) for support and protection against infection. Courtesy of the Department of Botany, University of Delhi.

the stock. The cuts are usually oblique, and the two surfaces are tied together with a tape and covered with wax (Fig. 47.3). This facilitates the union of the two cambial rings, and when such a 'composite plant' comes of age, its branches bear the cherished fruit (similar to the source tree which provided the scion) while the roots of the stock supply water and minerals.

Reproduction by Spores

The formation of spores is another common method of reproduction, especially in all those plants which have no seeds. Being very small and light, the spores can be carried to long distances by wind, water or other agencies. They are usually protected by thick walls, and can withstand the adverse conditions to which they may be exposed before they get a chance to germinate and form new plants.

In the unicellular and filamentous aquatic algae the contents of single cells divide into four, eight or more parts which change into motile spores called zoospores. When the parent cell wall breaks, the zoospores are released. They swim off to some favourable spot, come to rest, and give rise to new plants.

In some other kinds of plants, such as moulds, bryophytes and pteridophytes, the spores are produced in special capsules or sporangia. This would immediately bring to your mind the black sporangia of bread mould, clusters of sporangia on fern leaves and the capsules of mosses, each of which produces a large number of spores. The spore output of most plants is really enormous. A large puffball, for instance, may produce several million spores. These can be squeezed out of it in the form of a fine dust. Similarly the mushrooms produce innumerable spores on the 'gills' seen on the under surface of the umbrella. If you put a mushroom on a sheet of paper, the spores will be shed on it in the form of countless dots. Each sorus on the under side of a fern leaf may have as many as 200 sporangia, and each sporangium contains about 64 spores. The air currents carry the spores over large distances. Thus, it is hardly possible to expose a piece of bread without a few spores settling on it. If the moisture and temperature are favourable, the fungal spores produce new mycelia and make the bread mouldy.

There are innumerable forms of spores. It would indeed require a volume of the size of this book to describe them all. You have had an acquaintance with quite a few of these through your study of Section II. You can refresh your memory of some spore types by studying figure 47.4.

In both sporular as well as vegetative reproduction, sex does not enter into the process. For this reason both of these methods of reproduction are said to be sexless or asexual.

Sexual Reproduction

The third method of reproduction is the gametic or sexual method. The layman usually thinks that sexual reproduction is restricted to higher animals (vertebrates). He associates sexuality with the existence of two kinds of individuals, the male and female, each having a distinct external appearance. He also visualizes some kind of mating between the two sexes. However, from your study of the earlier sections, you would have seen that in most plants (and in some lower animals) the sexes are not separate. Quite often a single individual functions as the father as well as the mother

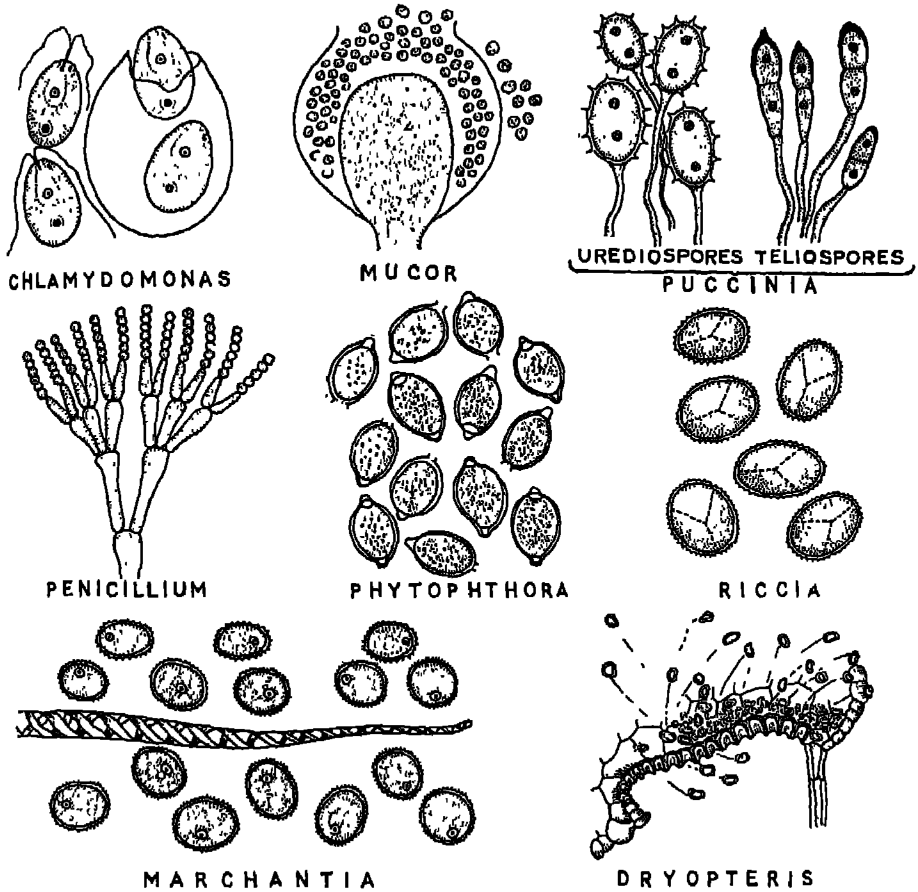

Fig. 47.4. A variety of spore types. Courtesy of the Department of Botany, University of Delhi.

of the offspring. In many cases, of course, things are so adjusted that it is the gametes from different parents that pair. However, this is by no means universal; cases of self-fertilization are not uncommon. Even where there are separate male and female plants, as in mulberry, the differences between the two are such that they can be understood only by a closer study. Moreover, the sexual process usually occurs in a very obscure manner as compared to that in higher animals. Excepting a few cases of conjugation (seen in *Spirogyra* and *Rhizopus*) there is no mating of the individuals. It is important to understand that in its bare essentials sexual reproduction comprises a pairwise union of the two sex cells or gametes. This is also called fertilization or **syngamy.** The cytoplasm as well as the nuclei of the two fusing cells thoroughly mix up to form a larger cell, the zygote, which grows into a new individual. The ways in which different kinds of organisms achieve the union of their gametes make a fascinating study. We shall review here only some cases from Section II.

The mode of sexual reproduction described for *Chlamydomonas* is perhaps the simplest. The small motile gametes are similar in shape and size. It is difficult to mark them as male and female, and yet the gametes themselves do seem to class themselves into two types. This is indicated by the fact that the gametes from the same cell usually do not fuse between themselves. They swim about till they find gametes coming from another cell.

In most other plants the gametes are clearly dissimilar, and the male and female gametes are then called sperms and eggs respectively. You should now recall the process of sexual reproduction in such plants as liverworts, mosses and ferns. In these the eggs are contained in archegonia while the sperms (antherozoids) are set free in water. The sperms swim down the open necks of archegonia, and one of them fuses with the egg which is a sedentary female gamete. Perhaps a sugary solution oozing from the archegonial neck attracts the antherozoids towards the archegonium.

The situation in seed plants is slightly different. Here two sperms are contained in the pollen tube. The egg lies in the ovule, and fertilization takes place when the pollen tube discharges the sperms into the embryo sac. The production of attractive flowers, the use of various agencies to bring about pollination, and other attendant events are all a prelude to this ultimate aim of bringing together the male and female sex cells in the act of fertilization. The fertilized egg or the zygote develops into a miniature future plant or embryo. Enclosed in the protective coverings the embryo, together with some food reserves, forms the familiar seed.

Has it occurred to you that the union of male and female gametes is largely a matter of chance? If the water in the vicinity of the antheridia of a fern suddenly dries up or becomes scarce, the chances of their swimming up to the archegonia become bleak. Similarly if the pollen is not deposited on the stigma or is deposited very late, no seed would be formed. In spite of the uncertainties, almost all kinds of plants and animals reproduce in a prolific manner by the sexual method. The only exceptions are the blue-green algae among plants, and certain protozoa among animals. You might then ask: Why should a plant waste its materials in this uncertain process of sexual reproduction? In other words, what is the great advantage of sexual reproduction?

The first advantage of this method is that the resulting offspring is always a little different from the parents. The exact reason for this will be explained a little later, but at this point it is enough to note that the differences or variations in the offspring result from the mixing together of the contents (cytoplasm and nuclei) of the two gametes. Obviously the differences would be more pronounced if the fusing gametes came from different parents than if they were derived from the same parent. As you will read later in Section VI, the variation brought about by sexual reproduction has played an important role in the formation of new species (evolution).

Secondly, the act of fertilization has a strengthening or rejuvenating effect. Consider once again the gametes of *Chlamydomonas*. They differ from the zoospores only in being much smaller. While a zoospore can develop into a mature *Chlamydomonas*, a gamete can normally do so only if it meets another gamete. If it does not find its partner it just perishes. Thus the act of fertilization bestows on the gametes a capacity for renewed growth. Further-

more, it has been seen that if a particular organism is artificially prevented from reproducing sexually for several generations, the vigour of the asexually produced progeny declines. The vigour may, however, be built up again if sexual reproduction is allowed to take place.

Maintaining the Chromosome Numbers

When the gametes fuse, the number of chromosomes in the zygote will naturally become doubled. The plant developing from the zygote will also have a doubled number of chromosomes. If sexual reproduction occurs again in this plant, the chromosome number of the third generation plants will be doubled once again. This progressive doubling would continue with each act of fertilization. However, this is not allowed to happen because the number of chromosomes is always halved during the formation of gametes. This is achieved by a special kind of cell division, called **reduction division** or **meiosis,** at some stage of the life cycle. The chief feature of this division is that from a diploid cell there arise four cells each of which has a monoploid number of chromosomes. A cell undergoing meiotic division exhibits the same stages as seen in its mitosis, namely, prophase, metaphase, anaphase and telophase. However, there are two consecutive divisions instead of just one, and each of the four cells formed at the end of a division has only half the number of chromosomes.

As noted in Chapter 4, there is a fixed number of chromosomes in the cells of any given kind of organism. In wheat it is 42, in maize 20, in onion 16, and so on. This number is called the diploid number and is symbolized as 2n number. You would also have noted that the diploid number, say 42, does not mean that their are 42 kinds of chromosomes, rather there are always two chromosomes of each kind. In other words the chromosomes are always in pairs. In the above examples there would be 21 pairs in wheat, 10 in maize, and 8 in onion.

When a cell enters meiosis, each chromosome becomes duplicated and shows two chromatids. This would mean that a diploid cell (2n) now becomes tetraploid (4n) by the addition of a chromatid to the original single chromatid of each chromosome. You would recall that the same change also occurs at the start of mitotic division. Next, instead of all the chromosomes lying independent, they come to be arranged in pairs. The strange thing is that each chromosome can somehow detect its partner and becomes associated with it. The two members of a pair are said to be **homologous**, i.e. they are similar in structure. One of the homologous members is paternal; the other, maternal. Since each chromosome now consists of two chromatids, a pair would naturally have four of them. When the division is completed, through metaphase, anaphase and telophase, one of the homologous members of each pair goes into one cell, the other into the second cell. There is no rule which obliges a particular chromosome to go into one cell and not to the other. Thus the two cells almost always get some paternal and some maternal chromosomes. The two cells immediately enter the second division. This time there is no duplication of the chromosomes, that is, no fresh chromatids are added. At the end of this second division four cells are formed, each cell receiving one of the chromatids from each chromosome. The separation of the chromatids each of which would eventually become a chromosome is again random, and each cell (which may

eventually become a gamete) comes to have half the number of chromosomes, some of which are paternal and others maternal (Fig. 47.5). In their nuclear make-up the gametes are almost never similar to the cell which produced them. When the gametes finally unite during fertilization, the paternal and maternal chromosomes are again brought together, and the zygote once again becomes diploid. One thing may be specially noted: due to random distribution of chromosomes in the gametes and an equally random union of the different kinds of gametes, limitless variations or differences would be realized in the sexually produced progeny. This mechanism accounts for the tremendous variety of characters in the individuals of the same species. In fact no two individuals are exactly alike.

Life Cycles in Plants

Among the plants that you studied in Section II, two general patterns of life cycle can be recognized on the basis of nuclear behaviour and the stage at which chromosome number is reduced. The first pattern obtains in such forms as *Chlamydomonas*, *Spirogyra* and *Rhizopus*. Let us consider here the life plan of *Chlamydomonas*. It passes the greater part of its life in the monoploid condition. It may reproduce asexually by forming zoospores, or sexually by producing gametes. The occurrence of one or the other type of reproduction is determined largely by the environmental conditions. In either case the reproductive cells arise by simple mitotic divisions of the parent cell. While the spores can directly grow into mature *Chlamydomonas* cells, the

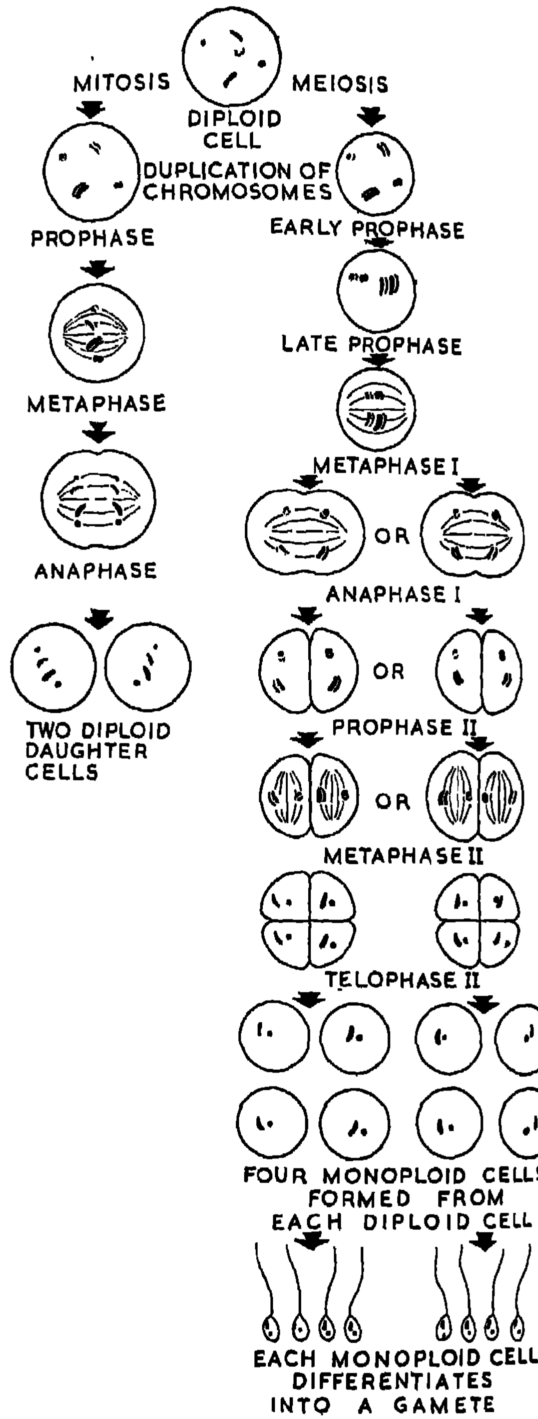

Fig. 47.5. Comparison of mitotic and meiotic cell divisions. Courtesy of the Department of Botany, University of Delhi.

gametes first fuse in pairs and form a zygote. The latter divides meiotically and the resulting zoospores are again monoploid. This condition prevails until zygotes are formed once again.

In the second type of life cycle, as seen in bryophytes, pteridophytes and seed plants, the most important thing is that the meiosis is postponed; it does not take place in the zygote but later in the life when spores are produced. In this type again, two variations have emerged. In bryophytes and pteridophytes, the zygote develops into a multicellular sporophyte or spore-producing plant (Fig. 47.6.) The sporophytes of bryophytes (*Riccia* and Moss) form an inconspicuous part of the life cycle and

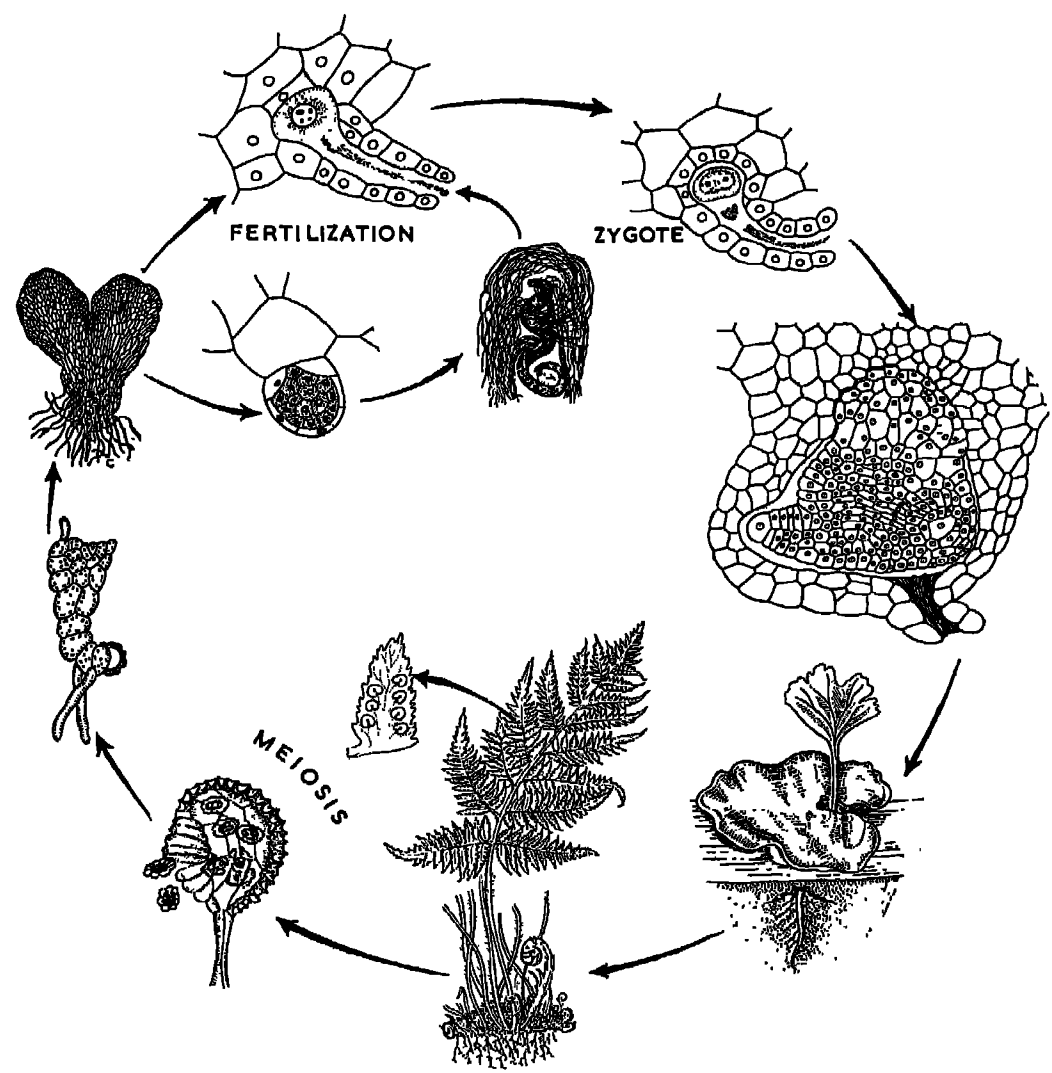

Fig. 47.6. The gametophytic and sporophytic phases in the life history of fern. The sporophytic (diploid) phase is shown in red; the gametophytic (monoploid) phase, in black. Courtesy of the Department of Botany, University of Delhi.

they are only partly self-reliant for their nutrition. In contrast, the sporophyte of pteridophytes forms the more conspicuous part of the life cycle and is self-sufficient. However, in both the groups the sporophyte is diploid and reproduces itself by means of spores. Meiotic division occurs at this stage, so that the spores are monoploid. The monoploid plants developing from the spores are distinct from the sporophytes. They are called gametophytes since they will eventually reproduce by means of gametes. The zygote, or fusion product of the gametes, again produces the sporophyte. In these groups, therefore, by the postponement of meiosis to the time of spore formation, two types of individuals or generations are formed, one responsible

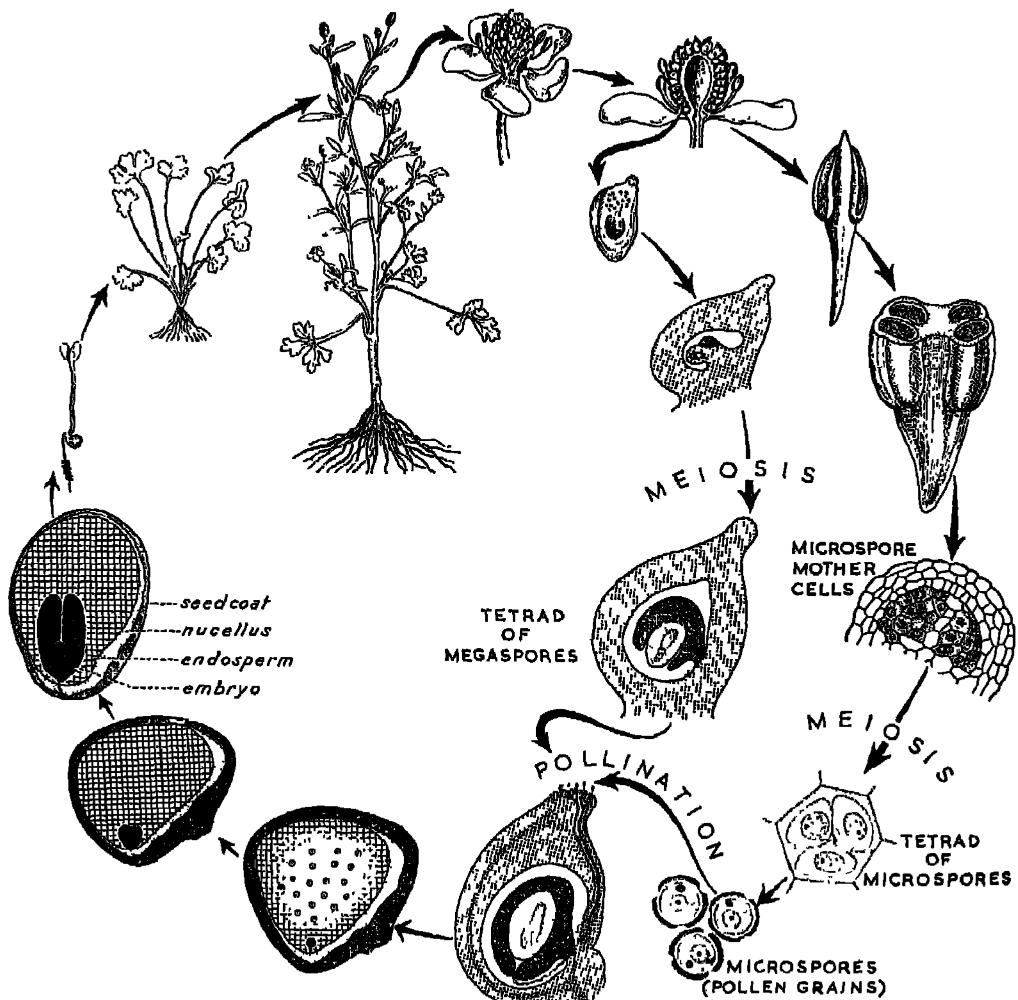

Fig. 47.7. Life-history of an angiosperm (*Ranunculus*). **Note the reduced gametophytic phase (shown in red).** Courtesy of the Department of Botany, University of Delhi.

for asexual reproduction and the other for sexual. The two generations normally alternate with each other in strict sequence.

In seed plants also, the reduction divisions occur during spore formation—when the pollen and the megaspores are produced in the anthers and ovules respectively (Fig. 47.7). The gametophytic generation in seed plants is highly reduced and has no independent existence. It develops and matures in the tissues of the sporophyte. What we see of a seed plant is the sporophytic or diploid generation. There are, no doubt, two generations as in the previous two groups but the gametophytic generation is reduced to the barest minimum.

SUMMARY

One of the most important attributes of life is the capacity to reproduce. The chief function of reproduction is the preservation of the species.

Broadly speaking, there are two methods of reproduction: asexual and sexual. In unicellular forms asexual reproduction occurs simply by the division of the cell into two or more parts. In multicellular plants asexual reproduction may occur by fragmentation, by spore formation or by the growth of detached vegetative parts such as leaves, stems and roots. In vegetative reproduction, the qualities of the parents are accurately preserved in the offspring. The superiority of the spores over the vegetative reproductive units lies in the fact that spores perpetuate the species not only in time but also in space. In the sexual method the most essential event is syngamy, or the union of two sex cells (gametes), to form a zygote. The gametes may be similar in appearance or clearly marked out as sperms (male) and eggs (female). Unlike most animals, plants are mostly bisexual, producing both male and female gametes.

When the gametes unite in sexual reproduction there is a doubling of the chromosome number. The diploid chromosome numbers of sexually reproducing plants are kept constant, generation after generation, by the occurrence of meiosis at some stage of the life cycle. Meiosis is a special type of cell division in which a diploid cell forms four monoploid cells by two successive divisions. The number of chromosomes in the gametes is always half that in the zygote. Sexual reproduction results in a great variation in the population of the species and keeps up the general vigour of the offspring. In most plants there are two phases or generations in the life cycle, a monoploid or gametophytic generation and a diploid or sporophytic generation.

QUESTIONS

1. Why do gametes have only a monoploid number of chromosomes?
2. Seedless oranges cannot be produced by planting seeds. How can you then account for the presence of millions of seedless orange trees in the orchards?
3. Some plants such as ferns, strawberries and mint grow in large, dense patches, while others occur singly. Explain.

4. Which plants will spread more rapidly to new localities: those reproducing vegetatively or the ones that produce seeds ?

5. Explain to a layman how sexual reproduction is possible without the male and female parents ever coming near each other.

6. Supposing you evolved a beautiful variety of rose. How would you go about producing more bushes exactly similar to the original ?

7. A branch from a tree bearing 'dasehri' mangoes is grafted on a tree that produces 'desi' mangoes. What type of mangoes will be borne on the grafted branch ? What type of mangoes on the other branches ?

8. At what stage of the life cycle does meiosis occur in:
   Chlamydomonas
   Spirogyra
   Rhizopus
   Moss
   Fern
   Wheat plant ?

9. List the advantages of propagating plants without using seeds.

10. What is a spore ? What is the significance of spores being produced so abundantly ?

11. Comment upon the following statements:
    (a) In spite of producing several million spores, a puffball may fail to produce other puffballs.
    (b) In asexual reproduction only one parent is involved while in sexual reproduction two parents take part.

12. Define regeneration. How have horticulturists made use of this phenomenon in propagating the desired types of plants ?

13. Grafting is seldom successful in monocotyledons. Explain.

14. Describe how the chromosome number in a sexually reproducing plant is kept constant.

15. How would you improve an individual plant in its own life span ?

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CHAPTER 48

Reproduction in Animals

IT is well-known that a large number of animals either die a natural death, or are killed by other animals and man. If all the existing members of a kind died, the species would cease to exist. Reproduction is the only means of its survival. As in plants, reproduction in animals may be either asexual or sexual. Most higher animals reproduce only sexually but some lower forms reproduce both asexually and sexually.

Asexual Reproduction

The simplest form of asexual reproduction is seen among the protozoans. Binary fission is common in the unicellular forms like *Amoeba*. The nucleus divides into two and this is followed by the division of the cell into two separate individuals. In other protozoans like *Paramecium*, which have a definite shape, binary fission occurs along a definite plane of the body (Fig. 48.1).

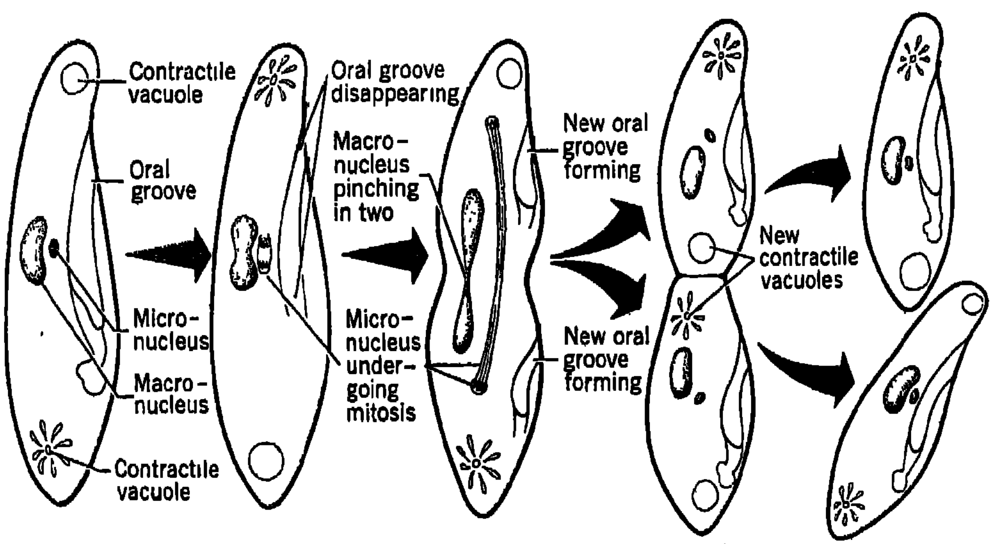

Fig. 48.1. Binary fission in ***Paramecium.*** From *BSCS, Biological Science: An Inquiry into Life,* Harcourt Brace & World Inc., New York, 1963.

The asexual phase of the life history of the malarial parasite, *Plasmodium*, involves multiple fission of a full grown parasite. Some protozoans become enclosed in a tough capsule or cyst which is capable of resisting extremes of heat and cold. In this encysted condition the nucleus divides several times, and ultimately a number of new organisms are produced. The encystment of the cells is also a method of self-preservation. This can be demonstrated dramatically by placing a handful of dry leaves (which usually carry a number of protozoans in encysted condition) in a jar of water. The jar will be found teeming with protozoans within two or three weeks.

Asexual reproduction also occurs in multicellular animals. In *Hydra* a bud may be formed as an outgrowth of the body wall. This bud grows into a small *Hydra* and breaks off from the parent to become a new individual.

Among many invertebrates, asexual reproduction is a method of increasing the number of young produced by each egg. This is exemplified by the life history of the liver fluke. The fertilized eggs are deposited in water. They hatch into free-swimming larvae which generally penetrate the body of a pond snail. Within the snail a series of other larval stages is formed. Since with each stage the number of larvae is increased greatly, a large number of offspring is produced from each egg.

In contrast to the profound capacity for regeneration in plants, in animals the ability to regenerate the complete body from a part is restricted to only a few invertebrates. Thus, as already mentioned in Chapter 30, sponges can be cut up into several bits, each of which can form a new sponge colony under appropriate conditions. Similarly flatworms, earthworms and starfishes can also produce entire organisms from parts (*see* p.490). A few other kinds of animals have a limited regenerative ability to replace one or more body parts if they are accidentally lost. For example, prawns can develop new appendages (legs, feelers, claws etc.) when the originals are cut off. Among the amphibians only salamanders are known to grow a new limb in place of the lost one. Fishes can regenerate fins. A lizard can afford to lose its tail when in danger and then grow a new one. However, in none of the vertebrates can a complete individual be formed from a part. In birds and mammals regeneration is limited mostly to wound healing, and not a single case is known of anybody having developed even the little finger afresh. In man, the liver, bone and muscle regenerate if not injured badly. Nevertheless, most animal tissues can grow indefinitely in tissue cultures.

Sexual Reproduction

In a large number of sexually reproducing animals there are two distinctly different kinds of individuals, males and females. The males produce sperms and the females produce eggs. The term egg also refers to the familiar hen's egg which contains yolk, albumen and a shell in addition to the female gamete, the real egg. Sometimes the same individual possesses the capacity to function as both male and female. Such an animal is termed hermaphroditic. A common example is the earthworm in which the male and female reproductive organs are present in the same animal. Hermaphroditic animals are rare among vertebrates.

The basic process of sexual reproduction in plants and animals is the same. Generalizations like syngamy and meiosis apply

equally well to animals. In most animals the individual is diploid and meiosis occurs during the formation of the sperms (spermatogenesis) and the eggs (oogenesis).

Gametes. The gametes exhibit many variations in size and appearance in different species. The sperms are microscopic and are produced in large numbers in all animals. Sperms move actively by lashing their tails. The egg is spherical or oval in appearance and is immotile. The eggs of different species are provided with varying amounts of food material in the form of yolk. Some variations in the appearances of the sperms and eggs are shown in figure 48.2. The eggs of birds and reptiles are large and heavily loaded with yolk, and are encased in a porous shell. The arrangement of the structures in the hen's egg at the time of laying is shown in figure 48.3. If a newly laid egg is opened by cutting the part of the shell which lies uppermost, a circular whitish area (blastoderm) is seen at the top of the yolk. The yolk is suspended in a viscous fluid called the albumen. The albumen on two sides of the yolk is thick, fibrous and twisted. The egg is covered over by a porous shell beneath which lies a papery membrane enclosing an air space on one side. In eggs which have been kept for some time after laying, the volume of the air space increases. An easy method of testing the freshness of an egg is to place it in water. A fresh egg always sinks whereas an old one keeps floating due to the presence of a large volume of air inside.

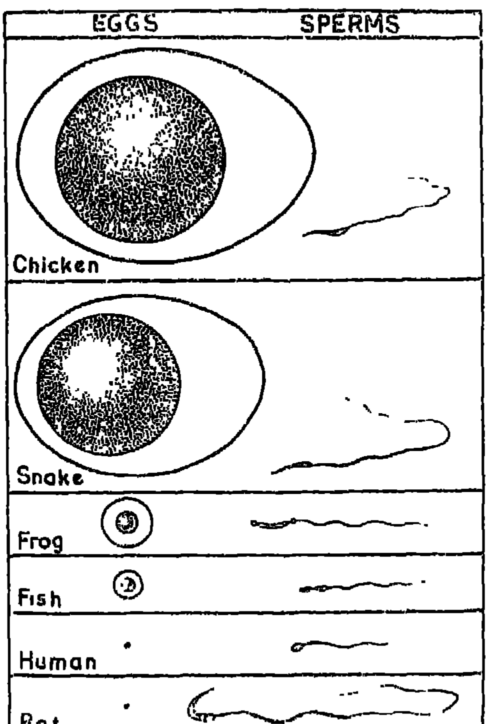

Fig. 48.2. Comparison of sizes and shapes of sperms and eggs of some animals. From *BSCS, High School Biology: Green Version*, Rand McNally & Company, Chicago, 1964.

Fertilization. In most of the invertebrates, fishes and frogs the sperms and eggs are shed into the water. The sperms and eggs of the same species are attracted towards each other and fertilization occurs outside the body of the parents. In other words, fertilization is external. Under such conditions many gametes are lost. This is apparently a wasteful method of reproduction. To compensate for such losses occurring before fertilization and at different stages during developent, animals with external fertilization produce a large number of sperms and eggs. The pearl oyster produces millions of eggs. In some fishes the sperms and eggs are laid close together so that the chances of their meeting are greatly increased. The male catfish deposits the spermatic fluid on the egg-mass laid by the female. The male three-spined stickleback (a kind of small fish) leads the female to a nest where she lays the eggs; then the male deposits the spermatic fluid

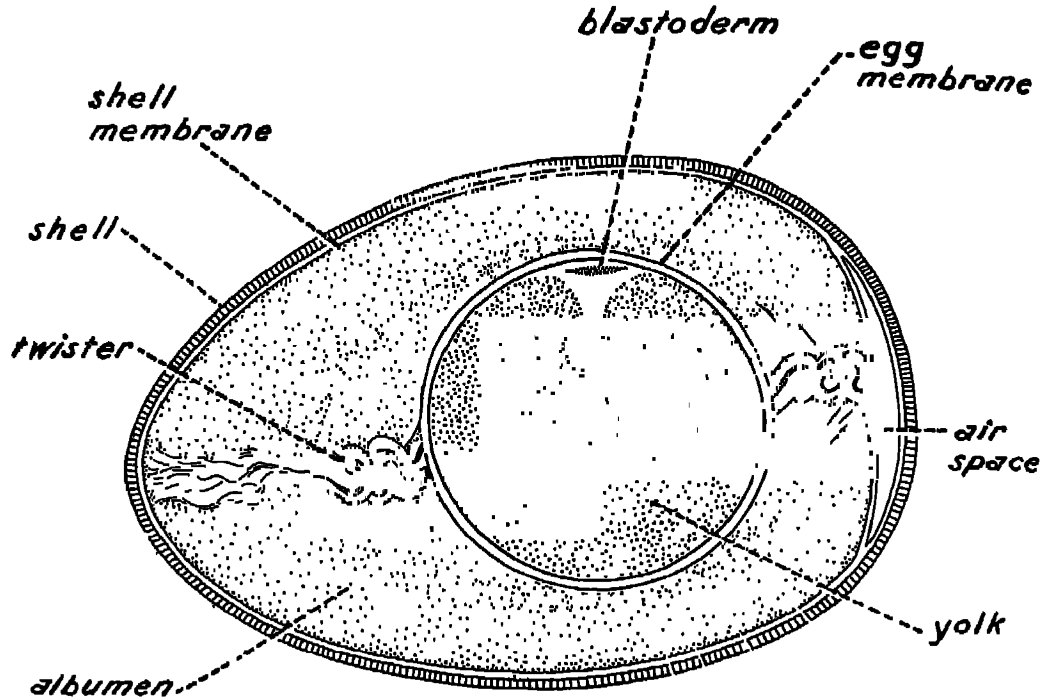

Fig. 48.3. Structure of hen's egg at the time of laying.

on the eggs (Fig. 48.4). In the common frog the process is carried a little further. The male climbs the back of the female and clutches her. As the female lays the eggs, the sperms are simultaneously discharged by the male.

In the reptiles, birds and mammals, sperms are deposited by the male inside the body of the female, and fertilization is therefore internal. Perfection of internal fertilization involves the development of many associated reproductive structures. Since the sperms do not have any stored food in them, they survive only for a very short time after being discharged. The eggs in turn can be fertilized only at a critical stage after they are released from the ovary. This calls for a precise timing in the mating of the males and females.

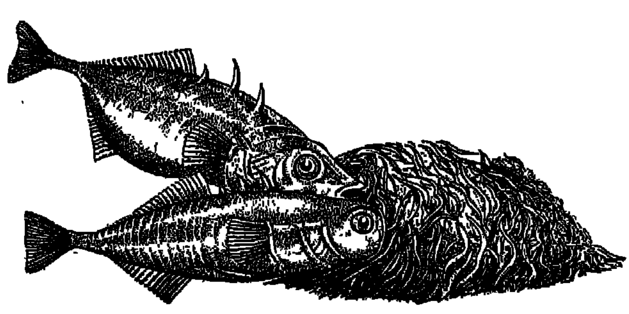

Fig. 48.4. Courtship in stickleback fish. The male leads the female to the nest to lay eggs and deposits spermatic fluid on them. From *BSCS, High School Biology: Green Version*, Rand McNally & Company, Chicago, 1964.

As an example of internal fertilization we may study the process in the rat. As in human beings, the reproductive organs of the female rat consist of two ovaries leading into coiled oviducts or Fallopian tubes. Each tube opens into a uterus. The narrow terminal parts of the two uteri open into a common cervix which leads to the external opening through the vaginal canal (Fig. 48.5). The sperms are deposited by the male rat in the vaginal canal of the female. From here they migrate through the uterus into the Fallopian tubes. The eggs released from the ovary also pass into the Fallopian ube, and it is here that fertilization occurs.

Artificial Insemination

Utilizing this knowledge of the methods of fertilization it is now possible to make the females of many animals pregnant by artificially depositing the sperms in the vagina. This is called **artificial insemination.** In many farm animals normal copulation or mating can be completely eliminated and replaced by artificial insemination. This involves the collection of the spermatic fluid from the males and storing it suitably for use subsequently. At any desired time small quantities of the fluid can be taken and introduced into the vagina or

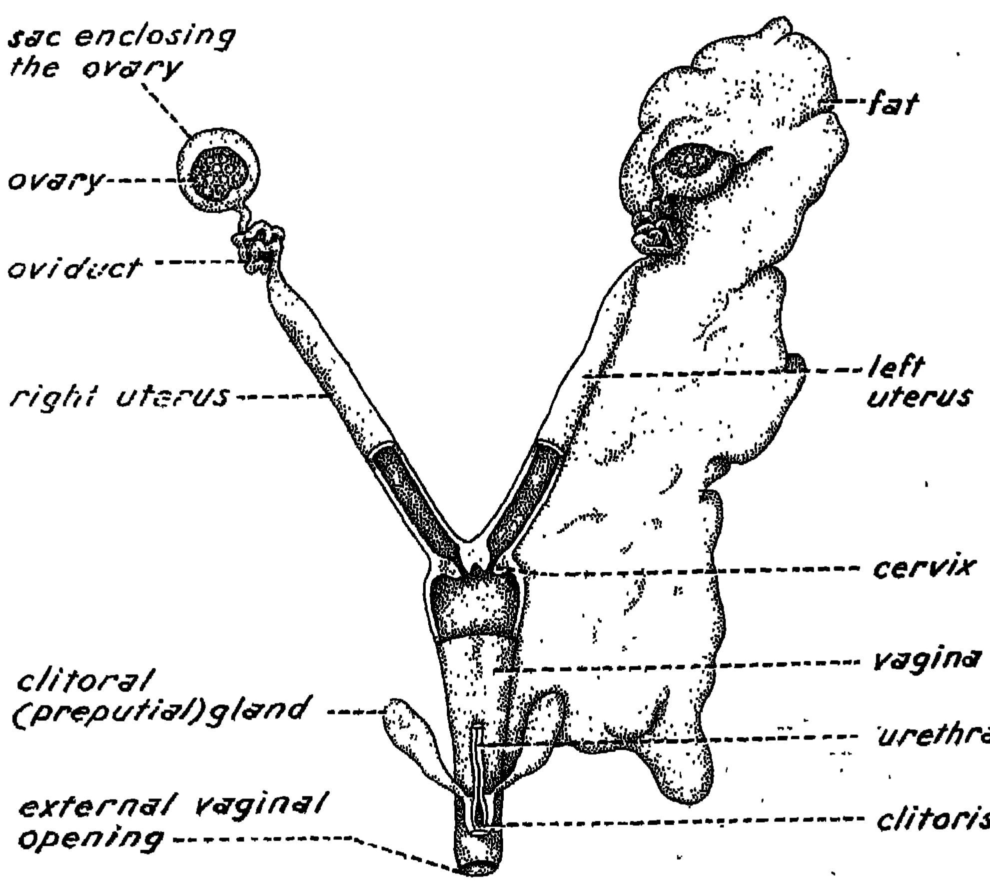

Fig. 48.5. Reproductive organs of a female rat. After C. D. Turner, *General Endocrinology*, W. B. Saunders Company, Philadelphia, 1962.

the uterus of the female. This method of initiating pregnancy in farm animals has two advantages. The spermatic fluid from a good quality bull or stallion (male horse) may be used to inseminate a number of females. The preserved fluid may be sent to distant places thus avoiding the necessity of transporting the male animals for purposes of breeding. Artificial insemination is one of the well-known and accepted methods for improving the quality of cattle and other farm animals. Artificial insemination using either husband's sperms, or sperms from another donor may also be used for human beings under medical supervision. Children born of such artificial insemination are called 'test tube babies'. Such a designation is, however, not quite correct because only the sperms are stored in test tubes and the babies are born in the usual way.

Development

In animals whose young develop outside the female body, the eggs are supplied with stored food in the form of yolk and albumen for the developing embryos. Moreover, the eggs are adequately protected by various coverings. Frogs lay eggs in water in bunches. The jelly surrounding the eggs serves to protect them.

Hen's eggs can be artificially incubated at a temperature of about 36-38C. At this temperature the chick is ready for hatching on the 21st day. The embryo is enclosed in a thin-walled protective sac which is filled with a fluid. The utilization of yolk by the embryo is accomplished by the development of a structure called the **yolk sac** (Fig. 48.6). Another large sac richly supplied with blood vessels is apposed to the porous shell, and facilitates the exchange of oxygen and carbon dioxide with the atmosphere. It also serves as a storehouse for excretory wastes from the embryo. The blood vessels from the developing embryo reach all parts of the yolk and albumen to pick up the nourishment.

The retention of the offspring on or within the body of the mother as a means for providing protection and nutrition is widespread and can be clearly understood by following the course of development in any mammal. Here fertilization is internal, and the development of the young occurs in a specialized portion of the body of the female. The fertilized eggs undergo some divisions and roll down into the uterus where the developing embryo attaches itself and establishes vascular contact with the tissues of the mother. A number of tiny finger-like projections grow from the outer cover-

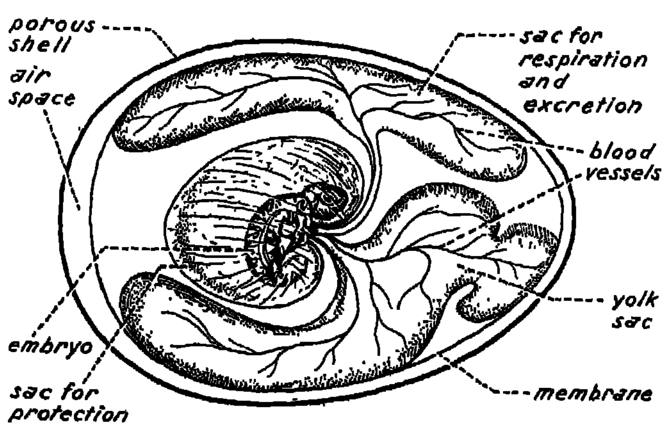

Fig. 48.6. A chick embryo. Note the formation of yolk sac. After L. Eisman and C. Tanzer, *Biology and Human Progress*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1958.

ing of the foetus (the developing young of a mammal) into the tissues of the uterus. Gradually, pools of blood form around these finger-like processes. It is through this vascular contact, called the **placenta,** that the foetus derives its nourishment and oxygen, and eliminates excretory wastes (Fig. 48.7). The blood systems of the foetus and the mother are never continuous with each other. The thin membrane that separates them allows the exchange of various substances by diffusion. The main blood vessels from the placenta enter the foetus through a thick cord called the **umbilical cord.** At birth this cord is cut, after which the baby ceases to draw its nourishment through the placenta.

Although the eggs of placental mammals are of nearly the same size, measuring about 0.1 mm in diameter, the size of the new born ranges widely. At birth, a whale weighs over a ton and is six metres long, compared to the mouse which is hardly two grams in weight and about 2-3 cm long. The number of young ones born each time varies greatly in different animals. The domestic pig produces 20 young ones at a time whereas in man, elephant, horse, cow and other large mammals usually only one young is born in a pregnancy. The duration of pregnancy also varies from 20 days in rats and mice to nearly nine months in man, 12 in cattle and about 21 in elephant.

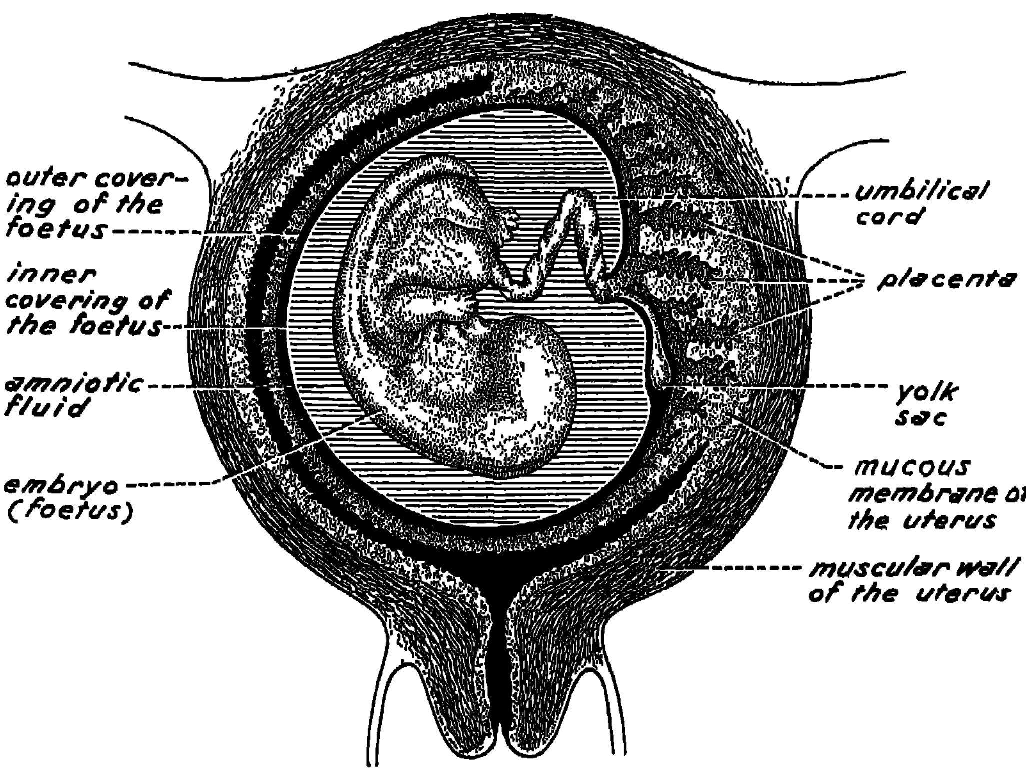

Fig. 48.7. Human foetus. Note the small yolk sac and the attachment of the placenta to the uterus.

Parental Care

Many invertebrates, fishes and amphibians spawn a large number of eggs. Such prolific egg laying is characteristic of the species living in water and those in which parental care is not well-developed.

Among the cartilaginous fishes we find many examples of vivipary, that is the eggs are retained within the uterus of the female and the young are born alive. In some sharks the yolk sac of each embryo attaches to the uterine wall of the mother through which the young obtains nourishment (Fig. 48.8). In the male sea horse (*Hippocampus*) an abdominal pouch is developed above the coiled tail. Fertilized eggs are placed in the pouch and the male incubates the eggs. The eggs of amphibians are generally fertilized externally and develop in pools and puddles. The male midwife toad (*Alytes obstetricans*) wraps strings of fertilized eggs around its legs and carries them on its body until they hatch. In the Surinam toad (*Pipa*) eggs are placed by the male in the depressions on the back of the female. These depressions are sealed until the tadpoles emerge. In the Javanese flying frog the eggs are laid in masses on leaves. The outer crust of these masses becomes hard while the interior remains watery. The tadpoles swim inside until the flooding of the fields when they escape out. In the European mountain-salamander the larvae develop in the uterus of the mother.

Some reptiles like the vipers and the sea snakes are viviparous and bring forth young ones. A few snakes like the python coil

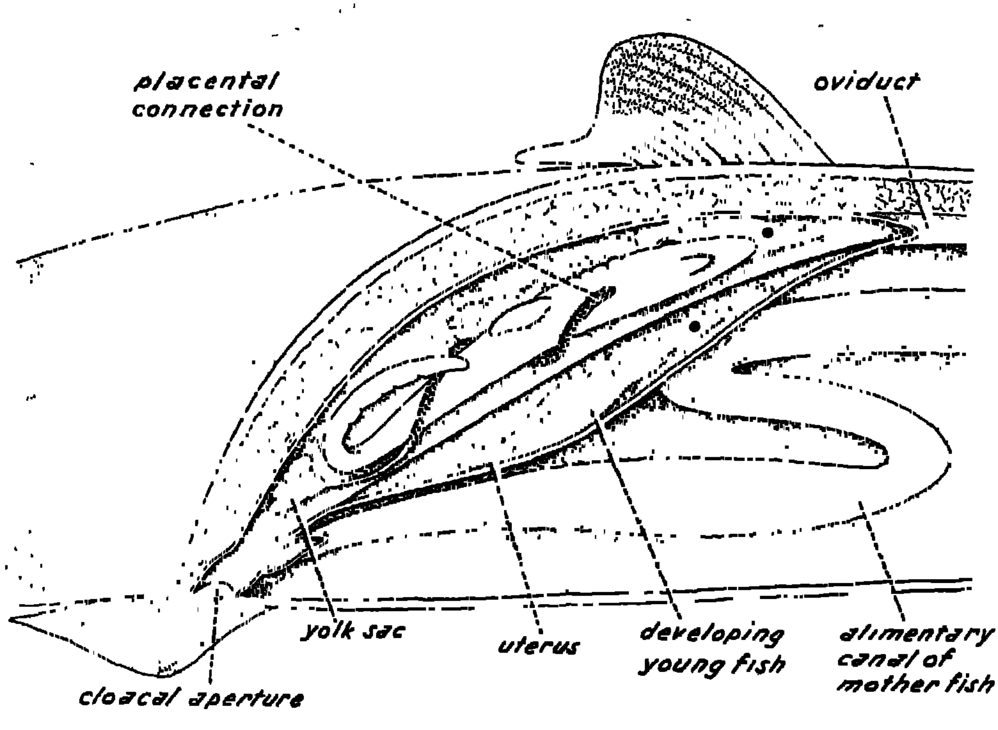

Fig. 48.8. The yolk sac of a shark. Each of the several embryos has a separate placental connection with the uterine wall of the mother.

around the eggs until they are hatched. Parental care is developed to a greater degree in birds (Fig. 48.9) and mammals. The young ones are taken care of by the parents for several months or even years after birth.

These yearly breeding cycles affect both the sexes equally although there may be slight differences in the timing between the maturation of the sexes. Before an animal can breed it must grow to maturity. The mouse may become pregnant when 6-8 weeks old whereas the elephant may not breed until the age of 15 years. In some animals, as in man, once the proper age is reached, breeding can occur throughout the year. Such animals are called **continuous breeders** in contrast to others which may breed during a restricted period of the year after reaching sexual maturity. The latter are called **seasonal breeders**.

Fig. 48.9. Parental care in birds.

Breeding Seasons

One of the most widely known and easily observable phenomena is the seasonal breeding habit of animals. The **breeding season** may be defined as that part of the year when an animal reproduces. The time of the breeding season is adjusted to the particular needs of a given species so as to afford the best chance for the survival of the offspring. A marine annelid found in the seas around Fiji spends the whole year hidden in crevices in the rocks, but in the months of October and November the animals swarm to the surface in large numbers, and spawn at dawn on the day before and the day on which the moon enters its last quarter. This act of spawning is so precise and accurate in timing that the natives of Fiji have included it in their calender.

Among mammals the young ones develop within the uterus of the mother who goes through a shorter or longer period of pregnancy. In such animals the two most significant events in reproduction, namely breeding and the birth of the young ones, are adjusted to the best advantage of the progeny when they are born. In mammals with a very short period of pregnancy (rabbit—30 days; field rat —21 days) a number of litters or sets of young may be born between spring and summer. In the larger mammals pregnancy is prolonged; hence the breeding season is separated from the season of birth. Sheep, deer and other ruminants breed during the autumn; following a period of pregnancy of about 150 days, the young are born either in late winter or early spring. The yak of Central Asia (a large, hoofed animal resembling the cow) breeds in July-August and after a pregnancy of about 260

days gives birth to the young in the following spring. In the horse and the ass pregnancy lasts for about 11 to 12 months. In such cases breeding in one spring is followed by birth of the young during the spring of the following year. In man, a continuous breeder, pregnancy is for 9 months, and the young are born at all times of the year.

The domestication of animals imposes on them continuous breeding in contrast with the seasonal breeding seen in the wild state. The mouse and rat breed throughout the year in houses although they show a regular periodicity in the wild state.

Hormones and Reproduction

The endocrine glands exert important and specific physiological effects on the reproduction of an animal. The endocrine gland which holds the key to all reproductive processes is the pituitary. It is attached to the ventral part of the fore-brain, and produces a number of hormones three of which bring about the stimulation and regulation of the reproductive processes.

In mammals the testes produce the **male sex hormone** called **testosterone.** This stimulates the secretory activity in the accessory glands of reproduction and the development of the **secondary sexual characters,** that is, such features as are always found in a particular sex but are not directly concerned with the process of reproduction. Secondary sexual characters are generally well developed in mature males and may be seen in the form of highly coloured combs and wattles of the cock, the antlers of the stag (male deer), and the mane of the lion (Fig. 48.10). The ovary produces two ovarian hormones called **estrogen** and **progesterone.** They play an important role in regulating the sexual cycle.

In man, apes and monkeys the sexual cycles differ from those in other mammals, and are known as **menstrual cycles.** They are characterized by the fact that during each cycle there is a time (menstrual period) when some loss of blood occurs from the uterus. This process is called **menstruation.** The release of the ovum from the ovary occurs in the middle of the 28 day menstrual cycle. If pregnancy occurs, the developing embryo establishes its contact with the uterus through the placenta and menstruation ceases. The maintenance of pregnancy and the birth of the young are regulated by ovarian hormones. After the birth of the young, the hormones help in the secretion of milk from the mammary glands. Milk production continues as long as the young are being suckled.

A knowledge of the varied aspects of reproduction can help us in devising methods for the prevention of pregnancy. India is a large country with a population of about 490 million people. Unless efforts are made to reduce the growth of population, the country will face an acute problem in finding food, shelter and occupation for millions of people. The Government of India have, therefore, launched a national programme of **family planning** to educate the people on the need to limit the size of the family and to acquaint them with the methods available for prevention of conception. The more we know about the intricacies of reproductive phenomena, the closer we move toward developing simpler methods for birth control.

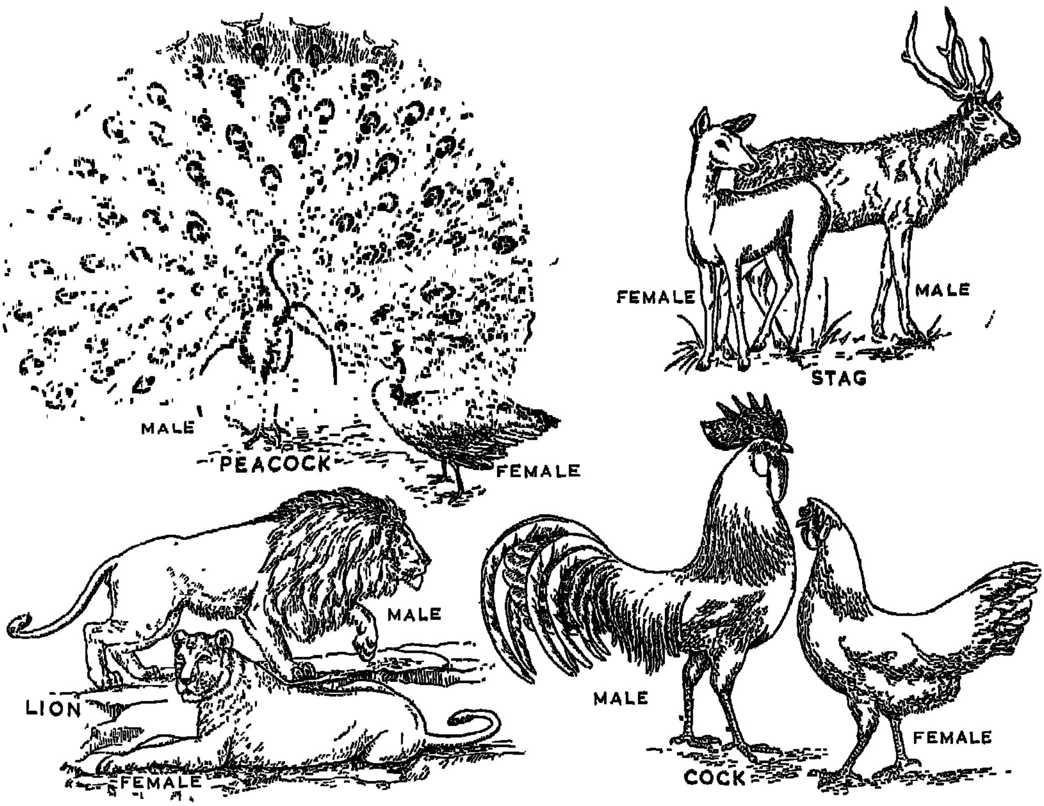

Fig. 48.10. Secondary sex characters in some animals. With a few exceptions, these characters are more pronounced in the males, and make them look more handsome than the females.

Parthenogenesis

Normally an egg develops further only if it is fertilized. An astonishing exception has been noted in the honeybee, certain wasps and other insects. In these, some of the unfertilized eggs develop into monoploid individuals. Such a development of an egg without being fertilized by the sperm is known as **parthenogenesis** (Gk. *parthenos*=virgin; *genesis*=descent). In honeybees, the queen mates with a male only once in her lifetime, and receives and stores several million sperms in a pouch in her body. She lays fertilized as well as unfertilized eggs. The former develop into female individuals (workers and a few queens), whereas the latter hatch into males. These are instances of natural parthenogenesis. The eggs of certain other animals can be artificially stimulated to develop by increasing the concentration of salts in the water (for eggs of sea urchin) or by pricking them with a needle covered with blood serum (for eggs of frog). Although there are several mythological stories about the parthenogenetic origin of human beings, there is no scientifically established case of such an occurrence in mammals.

Multiple Births

You must have observed that several puppies are born to a bitch but the birth of more than one baby to a woman is rare. Have you ever thought about how are twins born? Many superstitious and baseless beliefs have developed around such births. But actually twins are nothing more than freaks of Nature. The ovaries of a woman contain some 100,000 eggs, of which nearly 400 ripen in her lifetime. Normally a single egg matures every month and if it gets fertilized, a baby is born. Sometimes, however, it happens that two eggs mature together and on being fertilized, develop into twin babies. Such babies are called **fraternal** or **dizygotic twins**. They may be of the same or different sex and resemble each other as much or as little as ordinary brothers and sisters (Fig. 48.11).

In contrast to fraternal twins the **identical** or **monozygotic twins** are so exactly similar to each other that it becomes difficult to name them apart. They are almost al-

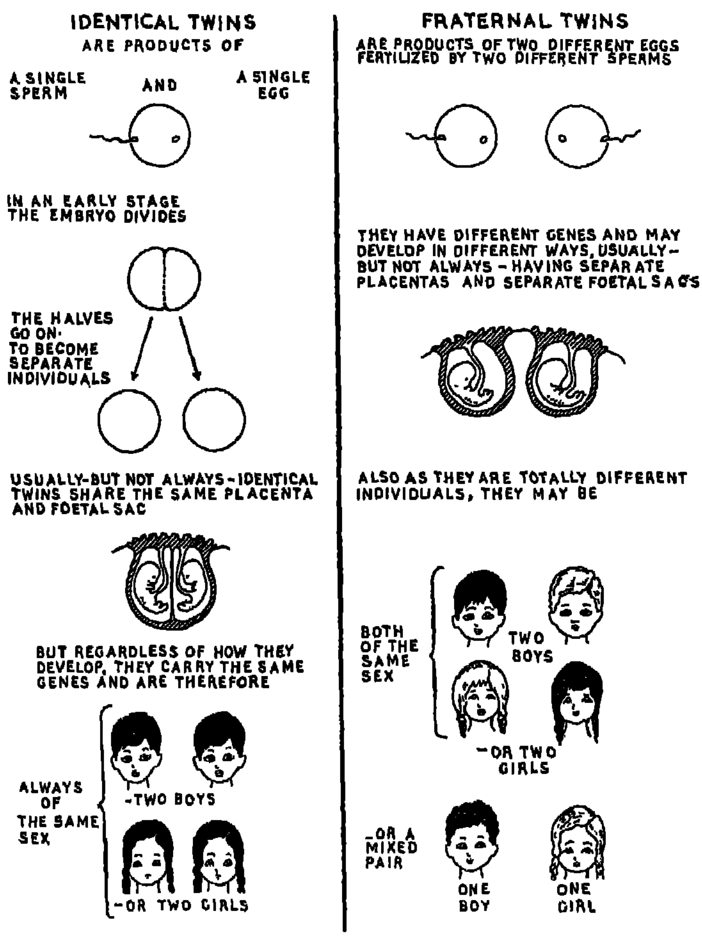

Fig. 48.11. The origin of two types of twins. After A. Scheinfeld, *The New You and Heredity*, J.B. Lippincott Company, New York, 1950.

ways of the same sex and show a remarkable similarity in their behaviour as well as abilities. Identical twins come from a single zygote. When the zygote has developed to the stage of a ball of cells (gastrula), it accidentally becomes pinched into two portions. Each portion then continues growth, so that two babies are born instead of just one. Sometimes the separation of the two cell masses is incomplete, and the twins are born attached to each other and remain so ever after. Such twins are called **Siamese twins** because the first well-known twin of this type was born in Siam (Thailand). Although multiple births occur by exception in man, in armadillo (a South American mammal) it is a normal feature. A reference to this was made earlier in Chapter 28.

SUMMARY

Although many superstitious beliefs still exist, new animals come only from their parents by the process of reproduction. Asexual reproduction occurs in protozoans and a few multicellular invertebrates, as hydra, sponges, and flatworms. In the latter, asexual reproduction occurs at the larval stage. As compared to plants, the power of regeneration in animals is very limited both in its degree and frequency. In animals sexual reproduction is the commonest and often the only method of reproduction. Even in hermaphroditic species the organs for the production of sperms and eggs are always separate. In all vertebrates and many invertebrates, the male and female individuals can be readily told apart.

Meiosis takes place during the formation of the gametes, and the animals are therefore diploid throughout their lives. As we study the methods of reproduction in different groups of animals we come across many interesting adaptations with regards to the method of fertilization and the subsequent development of the fertilized eggs. Where fertilization is external, there is a prolific production of eggs and sperms, and enormous wastage. Where fertilization is internal, egg production is limited, though the sperms are still formed in a large number. Again, if the eggs develop outside the body of the female, they are adequately protected and provided with food in the form of yolk. In mammals the young develop in the uterus of the females, and draw nourishment through a special structure called placenta.

Most animals are seasonal breeders though some like man and a few domesticated animals breed continuously.

There are isolated instances of parental care among the fishes and amphibians but the phenomenon is seen at its best in reptiles, birds and mammals. In recent years it has been possible to practise artificial insemination in cattle and horses. Multiple births result from the fertilization and development of more than one egg or by the accidental division of an undifferentiated cell mass produced from a single zygote. Multiple births of the latter type regularly occur in the armadillo.

QUESTIONS

1. What is the difference between:
   a. Internal and external fertilization
   b. Yolk and albumen
   c. The egg of a bird and that of a mammal
   d. Fertilization and artificial insemination
   e. Continuous and seasonal breeders
   f. Fraternal and identical twins?
2. What do you understand by parental care? Briefly describe it as seen in fishes, birds, reptiles and mammals.
3. Are the eggs of the following animals fertilized outside or inside the body?

   Mouse
   Fish
   Frog
   Parrot
   Honeybee
   Tortoise
4. Some people still think that earthworms are washed down with rain and that flies arise from filth. How will you convince such persons to the contrary?
5. How does a hen's embryo feed and respire inside the egg? How does it excrete waste matter?
6. Can a bird's egg be fertilized in the same fashion as that of a frog?
7. Which is more nourishing: the yolk or the white of an egg?
8. Define the following terms in your own words:

   Binary fission, multiple fission, conjugation, fertilization, gamete, parthenogenesis and secondary sexual characters.

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